Soil fertility management strategies in irrigated peri-urban agriculture around Jos, Nigeria—an interdisciplinary approach

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SOIL FERTILITY MANAGEMENT STRATEGIES IN IRRIGATED PERI-URBAN AGRICULTURE AROUND JOS, NIGERIA—AN INTERDISCIPLINARY APPROACH

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ABSTRACT

This thesis examines soil fertility management strategies in dry season irrigated vegetable production (DSIVP) in peri-urban areas of Jos, Nigeria. Farmers have developed a complex strategy of mixing inorganic fertilisers with organic manure and town refuse ash (produced by open burning, and sorting for non-combustible components). The thesis aimed to gain insights into the sustainability (in terms of nutrient supply) of the local agricultural system, acquire an understanding of past and present fertiliser practices and the rationale behind them, provide an appreciation of the role played by urban waste ash and the risks attached to its use, and place the problem of soil fertility in a wider context of farming problems. An inter-disciplinary approach was adopted so the methods used are: chemical analysis of soil and inputs (i.e. refuse ash), questionnaire surveys, semi-structured interviews (with farmers and PADP, JMDB, FUA etc.) and participant observation. The thesis observed that farmers have in-depth, but informal, empirically-derived knowledge about fertiliser application, which explains their past success in soil fertility maintenance. The tremendous increase in DSIVP in the last decade, though, has brought about a scarcity of organic amendments; farmers are increasingly reliant on inorganic fertilisers, probably over-applying them. Although this is not an immediate threat to the stability of the system, it may lead to soil acidification in the near future. Urban waste ash can counteract soil acidification (high pH and base cations), but certain batches can be contaminated by heavy metals, and indeed there is some indication of accumulation in the crops of the study farms. The problem of soil fertility needs to be addressed, however, farmers' short-term concerns (particularly access to credit facilities) need to be solved first. It is imperative that the Nigerian Government should take note of these issues and rapidly take steps to solve them.

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ABBREVIATIONS

AAS	Atomic Absorption Spectrophotometer
CEC	Cation Exchange Capacity
DSIVP	Dry Season Irrigated Vegetable Production
DTPA	Diethylene-triamine-pentaacetic acid
EDTA	Ethylene-diamine-tetraacetic acid
EEC	European Economic Community
FAO	Food and Agriculture Organisation
FGN	Federal Government of Nigeria
FUA	Fadama Users Association
IF	Inorganic Fertiliser
ISWC2	Indigenous Soil and Water Conservation
ITK	Indigenous Technical Knowledge
JMDB	Jos Municipal Development Board
JPERDP	Jos Plateau Environmental Resources Programme
MAFF	Ministry of Agriculture, Fisheries and Food
NADP	Nassarawa Agricultural Development Programme
NGO	Non Governmental Organisation
NFDF	National Fadama Development Facility
PADP	Plateau Agricultural Development Programme
PFI	Promoting Farmer Innovation in Rainfed Agriculture
PRA	Participatory Rural Appraisal
PTD	Participatory Technology Development
PUA	Peri-Urban Agriculture
PUI	Peri-Urban Interface
RPK	Rural People's Knowledge
SFM	Soil Fertility Management
ToT	Transfer of Technology
Tukey's HSD	Tukey's Honestly Significant Difference
UA	Urban Agriculture
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
WHO	World Health Organisation

DECLARATION

I confirm that no part of the material offered has previously been submitted by me for a degree in this or in any other University. If material has been generated through joint work, my independent contribution has been clearly indicated. In all other cases material from the work of others has been acknowledged and quotations and paraphrases suitably indicated.

STATEMENT OF COPYRIGHT

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DEDICATION

*In memory of my Grandfather, Mr A.C. Sinnicks,
whose kindness, love and wisdom inspired me
throughout my growing years.*

*To Dr D.R. Firn, whose passionate ideals and
thought-provoking courses motivated me to
undertake research in this subject.*

1 INTRODUCTION

The last decade or so has witnessed a tremendous increase in informal food production in city areas, particularly in those parts of the world characterised by economic collapse (Mbiba and van Veenhuizen, 2001). Urban and peri-urban agriculture (UA and PUA) can supply a significant proportion of food consumed within the city (Sweet, 1999), and is particularly important in the supply of perishable but nutritionally important produce, such as vegetables. In Africa, UA will necessarily expand, because already one third of the population lives in cities, and urbanisation is likely to continue rapidly in the next 25 years (Sonou, 2001). Despite the range of benefits it offers, UA has been strongly opposed by government agencies, and it usually remains marginal in the urban planning process. This is because there can be a variety of negative health, environmental, economic and cultural impacts (Binns and Lynch, 1998).

The favourable climate characterising the Jos Plateau makes it ideal for vegetable production. Market gardening was encouraged from the early twentieth century because of the tin mining in the area that led to the development of a large expatriate European community. The first major phase of market garden expansion, though, came with Nigeria's petroleum boom in the 1970s, that was, at the same time, accompanied by a decline in the tin mining industry (Porter, 1992a). The retrenchment of workers from tin mining forced them to take up dry season irrigated vegetable production (DSIVP). Survey work carried out in 1982 (Adepetu, 1985) and 1990 (Phillips-Howard *et al.*, 1990), showed that DSIVP was in a phase of expansion (mainly in accessible locations close to paved roads), and research carried out in 2001 (Porter *et al.*, 2002) demonstrated that this trend was continuing, not only in proximity to paved roads, but also wherever water was available for irrigation.

The tin mining industry left a devastated landscape of steep-sided mounds and numerous mine ponds, and minimal efforts were made at formal reclamation (Alexander, 1985). Alexander and Kidd (2000) have remarked that it is fortunate that this was the case. They contrasted the outcome of the institutionalised reclamation strategy, consisting of establishing *Eucalyptus* plantations, with the informal reclamation strategy adopted by the farmers. They found that the eucalypts did not progressively improve soil fertility. On the contrary, the fertility of already poor soils declined even further. By comparison, the reclamation strategy of the farmers was highly successful and, indeed, farmers possessed a complex fertiliser classification system and in-depth knowledge on how to improve the soils they worked with (Phillips-Howard and Kidd, 1991). The key to their success was the application of a mixture of inorganic fertilisers (IFs), manure and town refuse ash (Alexander, 1996; Alexander and Kidd, 2000). Town refuse ash is produced by open burning of urban waste *in situ*. As the urban waste consists of a mixture of materials, following combustion (which can take up to a week), the ash is sorted for leftover materials, such as plastic bags and containers, glass, and other non-combustible debris.

It is worth describing the history behind the development of this fertility strategy. The traditional approach to soil fertility management (SFM) consisted of the application of different manure types and household/wood ashes. In the 1970s, the Nigerian government decided to promote the use of IFs. Farmers told how they were convinced by extension agents to try the new fertilisers. They felt suspicious of the chemical fertilisers, so the extension agents prepared their own plots alongside the farms and grew maize, with the sole application of IF. They also left sacks of IF lying around the farming area to encourage farmers to try it out for themselves. When farmers witnessed the extraordinary development of the maize on the extension agents' plots, they started experimenting with the new fertiliser. They were not taught, at any stage, what the different chemical fertilisers consisted of. Farmers familiarised themselves with the new fertilisers and government policy encouraged this, importing large amounts of fertiliser, expanding domestic production, improving distribution of IF, and subsidising it heavily (Phillips-Howard and Kidd, 1991). Nevertheless, farmers did not switch completely to the new fertilisers. Instead, they continued combining different fertilisers, this time mixing the old with the new. In the 1990s, Phillips-Howard and Kidd (1991) reported that farmers were experiencing problems in accessing IF. When they asked them why they mixed fertilisers, they discovered that, in some cases, farmers were mixing because they believed that it was more beneficial to soil and crops and, in other cases, they were mixing to save on the costs of the more expensive types of fertiliser and as an adaptation to uncertain availability. In any case, farmers proved to be very knowledgeable about the effects of different types of fertiliser and had very clear ideas about what combinations were successful. Trial-and-error, for the most part, had generated this knowledge. It is fascinating how farmers have created a successful SFM strategy by blending old and new ideas. It shows that new ideas are not accepted as a whole package, but can be adopted, in part, or modified. Farmers are responsive to changing circumstances and can be very innovative. A good example is the way in which farmers made the transition from using household/farm ash to town refuse ash. They took advantage of the increasing quantities of refuse (from the growing urban centres on the Plateau), and the wider availability of motorised transport in the 1980s, to purchase truck loads of refuse, which they burnt and sorted on the farm site (Alexander, 1996).

The rapid development of DSIVP since the 1990s around Jos raises a number of important questions that this thesis has set out to investigate. The Jos Plateau has been held as an example of a situation where agricultural intensification has resulted in the local enhancement of soil fertility (Phillips-Howard and Lyon, 1994). Is this conclusion still valid today? The thesis tries to answer this by gaining insights into the sustainability of the system (in terms of nutrient supply), by carrying out soil analyses of certain case study farms to determine if nutrient demand of crops was being adequately met, and by matching soil data to information on changing socio-economic practices to establish the future direction of the system. This last information can be obtained by identifying critical characteristics of past and present SFM practices, and the rationale behind them. It is extremely likely that these practices will have been affected by the changing socio-economic circumstances connected to the expansion of DSIVP, and it is important to understand these issues in order to answer the question: has the evolution of SFM practices affected the stability of the system? The increasing integration of town refuse ash into the SFM strategy (as remarked on by Alexander, 1996) was especially interesting for two reasons. On the one hand, recycling waste into agriculture should be encouraged because it 'closes' the nutrient loop and contributes to the alleviation of the waste disposal problem (which is particularly acute in Nigeria). On the other hand, if it is not managed properly, urban waste can cause considerable health and environmental problems, by contaminating soils, crops and farm workers with various chemical substances and pathogens. As open burning of waste is a common means of treating it prior to application, in Jos there is the additional problem of airborne pollution. The third aim of the thesis was, therefore, to provide an appreciation of the role played by urban refuse ash in the system (and possibly investigate whether it could be improved or replaced by a more efficient alternative) and commence the process of assessing the health risks attached to using urban waste in DSIVP (this was done with preliminary analysis of the potential for heavy metal contamination). The final aim of the thesis was to place soil fertility into the wider context of general farming problems, which is necessary to understand how any recommendations for improved management strategies would be received by the farmers.

A key aspect of this thesis is that it sought to address these aims by drawing together different 'camps' of thought. Chambers (1983) divides the 'outsider' culture into the academic social scientists, who worry about the '*what?*' and the '*why?*' of development and underdevelopment, and the practical administrators and technical scientists, who instead are concerned with the '*how?*' Both sides are interested in alleviating rural poverty but, whereas the first seem involved only in the critical evaluation of the approaches to and outcomes of development policy, the practitioners involve themselves only in 'acting' vigorously and energetically and, not necessarily, to the best effect. Another fundamental difference is the way in which the two camps of thought explain rural poverty. Chambers (1983) states that many social scientists tend to explain poverty in social, economic and political terms (the 'political economy cluster' of views), whereas practitioners tend to explain poverty in physical and ecological terms (the 'physical ecology cluster'). Although he acknowledges that this contrast is far from absolute, and that there are overlaps and exceptions, he claims that generally: "*The political economy cluster sees poverty primarily as a social phenomenon; the physical ecology* *cluster sees it primarily as a physical phenomenon*" (Chambers, 1983, p. 34). Thus, he strongly advocates the need to close the gap between these two 'outsider' cultures but, very importantly, to include a third culture (the 'insider' culture), the rural people's culture. He stresses that rural culture must be seen as a centre of learning and attention, and, in fact, this idea is later developed into the 'Farmer First' paradigm (Chambers *et al.*, 1989), that is opposed to the 'Transfer-of-Technology' paradigm.

The whole of this thesis is, therefore, positioned at a crossroads of geographical, environmental and development research and, as such, it fully rests upon this notion of inter-disciplinarity. Inter-disciplinary research is exciting and intellectually challenging and, especially, in agricultural sciences, it is very important because it provides a more comprehensive view of the problem that is being researched: there is never one explanation for a problem and, hence, there cannot be one easy solution. Indeed, cross-disciplinary research (whether it is multi-disciplinary, or inter-disciplinary) is seen by an increasing number of authors to be essential to obtain a holistic understanding of research questions that, in fact, would not even arise within the boundaries of a single discipline (Harris, 2002; Jackson, 2002; White, 2002).

A final (but still very important) issue that needs to be considered is the implication of the results for the local poor: what do the results mean for the local farmers and how can they be of use to them? One of the original goals of the thesis (this was at the design stage, in the U.K., prior to fieldwork) was to design field trials in collaboration with the farmers to investigate the effectiveness of different fertiliser combinations. These fertiliser combinations would include treatments with various waste materials (such as urban refuse ash, compost, sewage, etc.). The idea behind this was that the soil analyses would provide information on which approach was most appropriate for soil fertility, and the farmers' input would ensure that the most suitable combinations be tested. In order to do this, the literature was consulted to choose appropriate participatory techniques. Unfortunately, when the time of implementing this plan came about, farmers were not interested. They consented to the field trials, but did not seem to be interested in being involved in designing them (the full details are provided in 4.6.3). For this, and other reasons, the field trials eventually became monitoring trials (where farmers continued with their activity as usual), because they could provide more useful information than if trials had been designed without farmers' advice. In retrospect, it is recognised that the intent of carrying out a fully participatory thesis was ambitious, but unlikely to succeed, because of the constraints of a PhD thesis. A PhD thesis cannot be open and flexible to change in the same way that a truly participatory development project can (clearly not all development projects are flexible and open). Had there not been a mismatch between farmers' priorities and the research objectives, or had there been more time to convince farmers (4.6.3), the field trials could have been a successful approach. Farmers, though, had other interests, and preferred giving their co-operation but not getting involved. Nevertheless, they made it very clear that they expected feedback from the thesis, regardless of whether it was of practical use to them or not. Over the course of the years, they had been interviewed by various people, some of whom, had not explained the purpose of their work and who had never returned to give them feedback. There was a sense of tiredness amongst the farmers, as they felt that they always collaborated but never saw any benefits from it. Thus, obtaining feedback was frequently a condition for granting an interview.

It is, therefore, very important to disseminate the results amongst the farmers. They may not have any immediate practical application, or farmers may choose not to act upon them but, nevertheless, farmers should be warned about any threats to their activity, or possible ways of optimising their strategies. At the very least, the act of returning the results will convince the farmers that their collaboration was appreciated, and it will maintain the climate of goodwill between farmers and any future researchers. The output of this thesis will, therefore, be returned to the farmers as soon as the PhD programme has been completed.

The thesis is structured as follows. Chapter 2 summarises the relevant literature and provides the backdrop to the research. It highlights the gap in the body of literature, which this thesis seeks to close, and sets out the aims and objectives of the research. Chapter 3 describes the physical features of the study area, the key characteristics of the farming population and the dry season farming practices. Chapter 4 addresses the methodology employed in the research process, describing fieldwork strategies in detail and also post-fieldwork activities (laboratory and statistical analyses). The successive four chapters each address an aim in turn, although there are links between different parts of each chapter, so that information from Chapter 5 contributes to the discussions in Chapters 6 and 7, and all the findings from the first three chapters are placed into a broader context under Chapter 8. Chapter 5, therefore, describes the characteristics and rationale behind current SFM strategies, comparing them to the past and providing insights into future trends. Chapter 6 provides an insight into the nutrient sustainability of the farming system by examining case study farms, and linking these results to the wider SFM practices, to make generalisations about the whole farming area. Chapter 7 examines one particular aspect of SFM, the use of town refuse ash, by providing data on the nutrient and heavy metal characteristics of ash in Jos, and analysing the farmers' views on the function of ash in relation to studies published in the literature. Chapter 8 places the particular problem of soil fertility maintenance into a wider context by examining general farming problems, from both the farmers' and the Plateau Agricultural Development Programme's (PADP) perspectives. Finally, Chapter 9 summarises the main findings of this thesis and identifies areas for future research.

2 THE WIDER AGRICULTURAL CONTEXT

2.1 URBAN AGRICULTURE

In developing countries a substantial proportion of the population lives in and around metropolitan areas and large cities. This includes an area that has been labelled the 'peri-urban interface' (PUI), where livelihoods depend, to some extent, on natural resources (Brook and Davila, 2000). There is no consensual definition of the PUI (see Mbiba, 2001, for a review), yet the need for this concept has emerged from the increasing recognition that the traditional urban-rural dichotomy is ill-suited to describe the fact that rural and urban features ever more coexist within cities and beyond their limits (Allen, 2001).

The great population pressure in and around cities, coupled with the economic collapse of many regions of the world (e.g. East and Southern Africa), have led to a tremendous increase in the last decade of total city area under informal food production (Mbiba and van Veenhuizen, 2001). This activity is known as urban or peri-urban agriculture (UA or PUA), but the problems surrounding the designation of what is urban (which Mougeot, 1994a, calls 'within' or 'intra-'), and what is peri-urban means that there is no universally agreed definition. Mougeot (1994a, p.1) has defined urban agriculture as: "*The production of food and nonfood plant and tree crops and animal husbandry (livestock, fowl, fish, and so forth), both within (intra-) and fringing (peri-) built-up urban areas*". Leaving definitional problems aside, a growing number of studies are demonstrating that UA is increasingly important for food production for both income generation and home consumption (Binns and Lynch, 1998; Egziabher *et al.*, 1994; FAO, 2000a; Mudimu, 1996). It has been estimated that urban farmers produce 15% of the world's food supply. Across the developing world UA produces significant proportions of the foods consumed: for example, 70% of the poultry consumed in Kampala comes from the city itself; Singapore is self-sufficient in meat and produces a quarter of its vegetables; Hong Kong produces two thirds of its poultry and almost half of its vegetables (Sweet, 1999).

Urban agriculture is practised for a variety of reasons. In Kampala, Uganda, four major household rationales were identified: commercial production, food self-sufficiency, food security, 'no other means' (Maxwell, 1994). The first group invests resources and capital in farming because it can be a lucrative business. The second group is oriented towards food self-sufficiency and only sells the surpluses to meet other purchases. The third group, which is the most common in Kampala, farms as a secondary activity. Income comes from elsewhere, but farming adds a little food security: rarely does the food get sold. The fourth group farms by necessity, because it is very low income and food-insecure. Frequently, though, it is forced to sell food to meet other expenses, even if the food then isn't enough to meet household needs.

The rising interest in UA derives from its wide-ranging benefits, which comprise:

1. Increasing urban food security;
2. Improved nutrition;
3. Improved sanitation solutions and waste recycling;
4. Improved physical and psychological health due to increased physical activity (Lock and van Veenhuizen, 2001).

Additionally, some authors have also pointed out that it can create employment for the jobless and provide various environmental benefits (Lynch *et al.*, 2001). This is not to say that UA has not been contested because of a variety of negative health, environmental, economic and cultural aspects (Binns and Lynch, 1998; Tinker, 1994; Mougeot, 1994b). On the health front the major risks include:

1. Contamination of crops with pathogenic organisms through irrigation with polluted water or inadequately treated wastewater or organic solid wastes;
2. The attraction of vectors carrying human diseases by the agricultural activity;
3. Transmission of diseases from domestic animals to humans during husbandry, processing or meat consumption;
4. Human diseases associated with unsanitary post-harvest activities;
5. Contamination of crops and/or drinking water by residues of agrochemicals;
6. Contamination of crops by uptake of heavy metals from contaminated soils, air or water (Lock and van Veenhuizen, 2001).

From an environmental perspective, a major risk is that of soil fertility depletion through nutrient loss by harvest removal, leaching and soil erosion (Quansah *et al.*, 1997). Although farmers could invest in soil improvement they frequently do not because of insecurity in land tenure (Tinker, 1994; Tacoli, 2001) and lack of funds. Furthermore, an expansion of agriculture could lead to increased competition for water resources, causing water shortages in arid and semi-arid areas, conflicting urban land issues, a lack of clarity over whether it is better to produce in the city or in the country, and a focus on urban cultivation activities rather than its position in relation to broader management issues (Lynch *et al.*, 2001).

The reaction to UA has been varied. In some situations, governments have taken a prohibitive stance, using strong measures to block this activity, judging it as harmful to health and the environment (Tinker, 1994). At other times, it has been ignored or dismissed as unimportant by scholars and agricultural planners, and is not taken into account by urban planners and developers. Even when a crisis situation forces structural changes to incorporate agriculture into city development, as soon as the crisis disappears the activity declines (as seen with the case of the allotment gardens in the UK from World War I to the present). Though the activity can re-emerge to serve new needs such as leisure and education, or as integrated with other uses of the land, planning ceases to give it a significant standing and leaves it to compete against other users of the same urban spaces (Mbiba and van Veenhuizen, 2001). Of course, these are generalisations, as different studies have shown that authorities are more or less accepting of UA, depending on the type of activity (vegetable production is favoured within city boundaries but livestock is generally not accepted), the spatial focus (peri-urban is more accepted than urban), and the beneficiaries (when UA is commercial rather than subsistence-oriented, city authorities are more prepared to integrate the activity and increase land security to farmers) (Mbiba and van Veenhuizen, 2001). Page (2002), provides an example of the political dimension of UA in Cameroon where, in his view, "*Urban agriculture is an 'anti-politics machine' in the design stage of production.*" (Page, 2002, p. 42). He warns that the ever-more common portrayal of UA as a panacea to the economic difficulties of the urban poor ignores the evidence of writers who point out instead that UA is not the most important source of urban food and that the poor are not always the major beneficiaries of UA. In Cameroon, UA absorbed the dissatisfaction of the citizens whose standard of living fell in response to structural adjustment policies in the 1990s. Although the government did not use planned interventions to organise UA more formally, it used covert measures to encourage UA to expand. The outcome of this was that farmers set out to reduce their bills in food markets, and ended up by assisting the elite to retain their power by diffusing social discontent. This outcome may not have been planned either by the farmers or the government but it highlights that any project that seeks to expand UA must consider political outcomes otherwise it may result in the 'entrenchment of state power'.

It is important always to retain a realistic perception of UA, without exaggerating its importance or conveniently downplaying its negative aspects. Urban agriculture has a role to play in supplying major cities with fresh and perishable year-round agricultural produce that is complementary to rural agriculture (Moustier, 2000). In Africa, in particular, it is estimated that as already one third of the population lives in cities and, over the next 25 years, the continued and rapid urbanisation is likely to lead to decreasing food security, there will be a need for further development of UA (Sonou, 2001). The extent to which this will happen is uncertain. Some authors have pointed out that there is evidence of a form of counter-urbanisation, where urban people with strong ties to rural areas move back to the rural areas, and in some situations this flow may actually exceed the rural-urban migration (Binns and Lynch, 1998). Furthermore, the development of UA will also be constrained by the demand for land by city dwellers (Moustier, 2000). Still, UA will be important in many cities and it will require proper management, so as to avoid health and environmental problems.

2.2 WASTE UTILISATION IN AGRICULTURE

Although there are proponents who believe that UA is damaging to the environment, others suggest that it could be the answer to a number of other important environmental problems (Binns and Lynch, 1998; Mougeot, 1994a). One of these is the problem of waste disposal. Urban centres can be considered vast nutrient sinks, because unlike rural areas, household waste and market refuse are not returned to production but contribute to urban pollution and health risks (Cofie *et al.*, 2001). According to Sweet (1999) urban centres produce most of the world's waste, and between a third and a half of this waste goes uncollected. In some African cities (Lagos, Ibadan, Kaduna, Enugu, Accra, Kinshasa) the situation appears even worse as figures for formal waste collection range from 11% to 44% for households (Asomani-Boateng and Haight, 1999). Yet urban waste has great potential because it can be exceedingly nutrient rich: the disposal of the waste on the urban plots could be, at the same time, a supply of nutrients and an alleviation of the waste disposal problem, i.e. the closing of the nutrient cycle (Gardner, 1998; Esrey and Andersson, 2001; Drechsel *et al.*, 2002).

There are many examples from the developing world of waste re-utilisation. Allison *et al.* (1998) provide a comprehensive review of this practice (not only for agricultural purposes). Many different materials are used all over the world as fertilisers: animal manures, green manures, composted town refuse, untreated town refuse, sewage sludge, waste water, night soil, etc. The literature on manure management is extensive, as obviously it is a widely used material: this topic has been reviewed for semi-arid West Africa (Harris, 2002), and recent examples come from work in the Kenya Highlands (Lekasi *et al.* 1998), and in the Kano close-settled zone (Harris and Yusuf, 2001).

In China, the practice of spreading night soil on fields is a long-established one. McGarry (1976) attributes China's rapid development after the 1930s to the continued use of night soil, which constituted a third of all fertiliser applied. Ling (1994) reports that after 1979 this practice diminished considerably and it is only recently that there has been renewed interest. His rough estimate is that night soil produced in urban areas would supply nutrients equivalent to 4 million tonnes of commercial IF, (4% of commercial fertiliser used throughout the country). Currently only 30% of urban night soil and 2.6% of city waste are being utilised, so there is potential for further use. In other countries the use of night soil is considered taboo. Nonetheless, the need for nutrients can be so high, that at times this aversion is overcome: in Ghana it was reported that farmers 'hijacked' government trucks that emptied septic tanks, and spread the night soil on their fields (Owusu-Bennoah and Visker, 1994).

China has developed another historically successful system: the dike-pond system (Korn, 1996). This intricate scheme revolves around the installation of a poly-culture fishpond.

Multiple cropping is practised around the pond on the dikes, and animals are raised near the household. Household waste and manure are fed to the fish, and rarely are extra inputs needed. Composted waste and urea can be added to the fields and occasionally the pond mud is dredged up and applied too. The system is highly productive (it rarely needs external inputs) and cultivation is continuous. Similar schemes are being operated in Thailand (Dalsgaard and Olsen, 1995; Little *et al.*, 1996), India (Sharma *et al.*, 1997), the Phillippines (Lightfoot *et al.*, 1994), Malawi (Brummet, 1994), and have been tested in South Africa (Prinsloo and Schoonbee, 1987).

In Senegal composted household waste has been used around the town of Louga, where the application of 100 tons per hectare to cabbage crops raised productivity fourfold, compared to untreated land (Haramata, 1991). Around Thies, refuse has been applied directly to the fields, without any treatment or sorting to remove non-biodegradable products (Haramata, 1991). Local NGOs have been attempting to discourage this practice or at least introduce waste sorting at the household level, as domestic animals are reportedly dying because of consuming plastic rubbish in the fields (Francesca Sacchi, Pers. Comm., 2000). In Calcutta, solid waste has been used for a long time in agriculture, and there is an organised system of rag pickers who sort the waste. The remaining organic component then goes onto nearby farms (Kundu, 1995, 2001; Mukherjee *et al.*, 2001). Lardinois and van de Klundert (1994a,b) report cases of small-scale recycling initiatives to recover organic waste from town refuse in Manila, Calcutta, Cairo, Accra, Bamako and Nairobi. In Bamako, Mali, the waste is transported to landfills where it lies undisturbed for a long period. After this 'natural' composting process, entrepreneurs separate out the impurities with relatively simple tools (sieves, brooms, spades) and obtain good quality compost that is in high demand. In the same city, in 1992, graduates were involved in a more organised composting project called GIE BESEY. In Cairo, Egypt, the Zabbaleen, a group of Coptic Christians, have been central in collecting household waste, sorting it, and sending the organic component to a windrow composting plant. The resulting compost is in high demand, but analyses in 1991 showed that there were high levels of zinc and lead and dangerous levels of cadmium.

Other materials that can be usefully applied to agriculture are municipal incinerator ash, coal-fly ash or wood-fired ash. Most studies, though, seem to have been concentrated in developed countries and not necessarily in (peri)urban areas (e.g. El-Mogazi *et al.*, 1988; Ghodrati *et al.*, 1995; Sims *et al.*, 1995; Vance, 1996; Zhang *et al.*, 2001; Zhang *et al.*, 2002). Some work has investigated the benefits of mixing coal-fly ashes with various bio-solids to improve the nutrient availability of the mixtures (Schumann and Sumner, 1999), and experiments have been carried out quite recently in India (Shore, 2000). There are many examples of informal utilisation of waste ashes in developing countries. Wood ash and household waste ash have long been traditional soil amendments (Foth and Ellis, 1997): for example, women in Eastern Tigray use cooking ash on their plots as fertiliser, and one woman used ash from kilning her pottery and found it to be an excellent soil enhancer (Abay *et al.*, 2001). In Nigeria, in Zamfara Forest Reserve, ash is one of the constituents of farmyard manure (Hoffman *et al.*, 2001). In the Kano close-settled zone, farmers apply ash in pure form (derived from household refuse or by seasonally burning crop residues), or mixed with manure (Harris and Yusuf, 2001). Around the town of Jos, farmers were reported to use a variety of fertilising materials, including cooking fire ash, farm waste ash (Phillips-Howard and Kidd, 1991), and urban refuse ash (Alexander, 1986). While cooking fire ash or farm waste ash were traditional soil amendments used typically in combination with poultry manure, the practice of using town refuse ash probably arose in the late 1970s. Certainly it was witnessed in the Rayfield area, close to Jos, in 1982 (Alexander, Pers.Comm., 2002). The practice of using urban waste derived ash has been observed in other countries, such as India (Bradford, Pers. Comm., 2001), but it does not seem to have been formally documented in the literature.

The examples outlined above deal with the solid component of urban waste but it must be noted that there are many instances of wastewater utilisation for irrigation. Indeed it has been estimated that 10% of the world's population eats food produced with wastewater (Smit and Nasr, 1992, as cited by Parkison and Tayler, 2001). Wastewater can be of great importance in arid climates where water is a limiting factor, and can also contribute significant amounts of nutrients, which reduces the dependency on fertilisers (Niang, 1999). Farmers can also be motivated to use wastewater because it is cheaper than pumping groundwater to irrigate crops (Parkinson and Tayler, 2001). Examples of wastewater utilisation come from Senegal (Niang, 1999; Gueye and Sy, 2001), Ghana (Sonou, 2001), Burkina Faso and Mauretania (Gueye and Sy, 2001) and many other countries, both in Africa and Asia.

Urban waste utilisation can offer a number of benefits (from alleviating the waste disposal problem to reducing the dependency on IF), but it can also pose numerous health risks. As mentioned in section 2.1, the major risks affecting UA have been summarised by Lock and van Veenhuizen (2001). Usually, most attention has been devoted to the issue of toxic heavy metals, rather than pathogen contamination. Furedy (2001) points out that in Northern countries, compost standards are still based on heavy metal concentrations even though it is known that pathogen contamination can be a major risk. Micro-organisms from the waste can be transmitted by direct ingestion of the soil or compost by children, by indirect contamination of the vegetable crops or through atmospheric dispersion in the waste dust (Déportes *et al.*, 1995). Although Northern countries are starting to question the validity of the current compost standards, developing countries frequently do not have standards at all, and even when they do, they are based on heavy metal concentrations. Still, some authors question whether developing standards based on pathogen contamination in developing countries would be at all practical and whether, perhaps, it is not better to just control the composting process (Furedy, 2001). Providing that the compost heaps reach sufficiently high temperatures for appropriate lengths of time (55° to 70 °C, for about three days), composting effectively kills most of the pathogens that would be otherwise present in raw organic waste (Asomani-Boateng and Haight, 1999). Unfortunately, the situation is complicated by the fact that urban farmers do not only use compost, but may also use sewage, wastewater or raw waste. It is very difficult to introduce health regulations as, for example, work in Burkina Faso, Mauretania and Senegal has shown that farmer knowledge on the cause and effects of disease is limited and for this reason producers are reluctant to give up using wastewater (Gueye and Sy, 2001). In Jos, Nigeria, market sellers wash vegetable produce in river water, which can spread typhoid and other diseases. Toxic heavy metals can be found in various types of waste and can be assimilated by human beings either by direct ingestion of the soil or through plant uptake and accumulation in the food chain (Risser and Baker, 1990). Excessively high levels of heavy metals in vegetables irrigated with wastewater have been found in Dar es Salaam, Tanzania (Bahemuka and Mubofu, 1999), and in the compost from the Zabbaleen plant in Cairo, Egypt (Lardinois and van de Klundert, 1994b).

A problem that is specific to the production of town refuse ash is the practice of uncontrolled burning. Even controlled municipal incineration of waste is subject to a variety of environmental problems such as particulate and gaseous emissions containing heavy metals, polychlorinated dibenzodioxins (PCDD), polychlorinated dibenzofurans (PCDF), polycyclic aromatics (PCA), polychlorinated biphenyls (PCB), acids and other compounds (Lisk, 1988). Modern incinerators are equipped with pollution control devices to minimise these emissions, but in the setting of peri-urban agriculture, farmers practice open burning without sorting the waste. This will, undoubtedly, result in toxic fumes being discharged directly into the atmosphere and, furthermore, certain contaminants in the waste can result in the deposition of toxic compounds and heavy metals in the ash itself (Déportes *et al.*, 1995).

2.3 THE NIGERIAN SETTING

In 2000, the population of Nigeria was estimated to be some 113,862,000, with 50,086,000 living in urban areas. Its total economically active population was 45,129,000 of which 15,030,000 were engaged in agriculture (including hunting, forestry and fishing). In 1999, it was estimated that 69,938,000 ha of land were used for agricultural purposes, 233,000ha of which were devoted to irrigated agriculture (FAO, 2000b)

The agricultural sector in Nigeria has suffered a consistent decline since the 1960s. Faced with soaring food prices and increasing expenditure on food imports, the government has tried to promote, on several occasions, various programmes to boost food production but these attempts have not met with much success (Gbadegesin, 1991). Rural producers prefer concentrating on cash crops rather than food crops (Gbadegesin, 1991) and, consequently, this has been translated into food shortages, particularly for urban dwellers. As a result, there has been an expansion in urban cultivation in several cities (aided by the economic decline and the lack of funds to import food): in Ibadan, farmers are mostly low-income earners who produce mainly to reduce their expenses on food and to supplement the family's income (Gbadegesin, 1991). Similarly, farmers in Kano produce mainly for home consumption and use the money gained from produce sales to buy supplementary foodstuffs and meet various other financial obligations to their families (Lynch *et al.*, 2001). Vegetable production around Nsukka is a means of sustenance to the farmers and an affordable means of satisfying nutritional deficiencies (Agunwamba, 2001). In contrast, production on the Jos Plateau has a commercial orientation and is clearly focused on supplying markets in southern Nigeria (Porter *et al.*, 2002).

The country also has an enormous waste management problem, and at the core of this is the fact that government policies on the environment are piecemeal, where they exist, and poorly implemented (Agunwamba, 1998). All over Nigeria there are examples of unsanitary, open dumps, and industrial contaminants are continuously discharged into streams and rivers without treatment. The waste collection system has virtually collapsed in many cities: in 1982, it was noted that in Kano there were 40 operative waste disposal trucks, but by 1995 these were reduced to five or six (Lewcock, 1995). Similarly, the waste collection scheme in the town of Jos in Plateau State was commissioned with 23 waste disposal trucks in the 1980s, but by 2001 these were reduced to just four (see 5.6.7). The absence of an effective waste disposal policy causes considerable environmental problems, and peri(urban) farming has most likely contributed to the alleviation of the problem in some cities. Kano has a long history of using urban solid waste. In the 1960s, during the dry season, there was an intense exchange of two commodities in large demand in the town and country respectively, and these were firewood and manure (Mortimore, 1967). In one week, approximately 13,000 donkeys converged on the city from all directions, carrying loads of fuelwood. Most came from distances of less than 10 miles from Kano, and many returned to the country with manure loads (at least 9000 donkey loads per week, representing 1000 tons of manure). By the late 1980s, the situation had changed considerably as fuelwood was coming in from much further afield, the donkey trade had almost ceased (Cline Cole *et al.*, 1990), and had been replaced by pick-up trucks delivering rubbish (a minimally composted material composed mainly of street sweepings and household refuse) at roadside locations only. A study carried out in the mid 1990s showed that urban waste was highly valued by the farmers, who complained that it had become more difficult and expensive to obtain, mainly because of the near-collapse of the State waste disposal service (Lewcock, 1994, 1995). The practice of using urban waste in agriculture is not limited to Kano, it has also been documented in Jos. The difference here is that the waste is not composted but burnt and applied as ash, in combination with other fertilisers (Alexander, 1986; Phillips-Howard and Kidd, 1991). Using household refuse ash or cooking ash as a fertiliser is not a novelty *per se*. It is a traditional amendment and its use has been reported in various other parts of the world. In Nigeria, some authors have noted that it is one of the ingredients of farmyard manure in a rural area in Zamfara Forest Reserve, northwest Nigeria (Hoffman *et al.*, 2001), and in the Kano close-settled zone (Harris and Yusuf, 2001; Harris, 2002). What is exceptional is the fact that peri-urban farmers around Jos have made the transition from using household refuse ash or wood-fire cooking ash (or in some cases even manure ash) to using town refuse ash. Although it is likely that this occurs in other cities too, currently it appears to be the only documented example in the literature.

There are also some examples of formal scientific research on the use of organic amendments in agriculture, carried out by local university researchers (e.g. from Ahmadu Bello University in Zaria State, Enugu State University, University of Nigeria in Nsukka). Agbenin and Goladi (1997) report on a 45-year study based at Samaru on the effects of mixing different levels of manure and IFs. They found that farmyard manure applied alone or in combination with IF was effective in sustaining soil quality under continuous cultivation, by maintaining carbon, nitrogen and phosphorous levels equal to or greater than native site soil. In contrast, continuous IF application was deleterious to soil quality because of organic matter depletion (the store of plant available nitrogen and phosphorous). Mbagwu (1992a, b) carried out trials around Nsukka, on the effects of rice shavings, poultry manure, and IF, singly and in combination. He found that organic amendments were superior to inorganic amendments in reclaiming eroded soils, but would have to be applied every year at high rates because of their low residual effects. This raised problems of feasibility as the farmers of the area lacked the financial resources to obtain such large quantities of organic amendments. Mbagwu *et al.* (1994) used dehydrated swine waste (DSW) in combination with IF and generally found that where DSW was used, the physico-chemical properties of the soil were improved. Anikwe (2000) experimented with rice husk dust and concluded that 4.5t ha^{-1} of this material was appropriate to ameliorate the physical properties of a clayey soil because it improved water flow and soil aeration and, hence, soil productivity. One study is particularly interesting because it focuses on both the environmental and socio-economic impacts of wastewater irrigation (Agunwamba, 2001). Around Nsukka, the urban poor use the effluent from waste stabilisation ponds to cultivate vegetables. The author found that wastewater irrigation elevated the mineral content and salinity level (although various other conditions meant that there was a low-risk salinity hazard) of the soils. He believed that there was a trend of nutrient depletion because of decreased availability of wastewater, siltation of ponds, a poor system of land cultivation and an increase in the area of land cultivated. Indeed, the decreasing soil fertility coupled with declining availability of wastewater was motivating farmers to purchase IF. From a health perspective the utilisation of wastewater had negative impacts because there was significantly greater incidence of diarrhoea and typhoid fever amongst those who came into contact with the wastewater, and the incidence of diarrhoea, but not typhoid fever, was significantly higher in consumers of vegetables irrigated with wastewater compared to the non-consumers. Furthermore, as waste stabilisation ponds provide a breeding ground for mosquitoes, malaria was more prevalent amongst people living close by rather than those living far away from the pond.

The Jos Plateau has been the subject of intensive research, particularly under the EEC sponsored two-phase Jos Plateau Environmental Resources Development Programme (JPERDP). Phase I (1982-1986) focused on carrying out basic scientific studies, analysing data and identifying problems. Phase II (1988-1992) continued and extended the research and training components, and concentrated on searching for appropriate interventions to problems through field experimentation. The research process was people-oriented so that prevailing constraints and available resources would be recognised and used to develop the most relevant and feasible recommendations (Olaniyan, 1992). The programme resulted in numerous reports, many of which provide a historical background to the current thesis. For example, Report 2 (Adepetu, 1985) described and compared *fadama* farming in four locations on the Jos Plateau. Report 18 (Phillips-Howard *et al.*, 1990) was aimed at investigating the changes in farmer characteristics, farm characteristics and other exogenous factors (market access, transport, etc.) between 1982 (using Adeptu's 1985 report) and 1990. Report 17 (Phillips-Howard and Kidd, 1990) contains material concerning the farmers' identification and perception of the major agricultural-related problems they faced and the solutions they put forward. Report 25 (Phillips-Howard and Kidd, 1991) described and analysed the farmers' SFM strategies. In particular, soil amendments used were identified and ranked according to the farmers' own classification. The farmers appeared knowledgeable in comparing the different fertilisers, identifying useful combinations and their relationship with crops. Other reports were of interest because they provided information on the history of mining activities on the Plateau and the characteristics of mine land soil (part of which was subsequently reclaimed through farming) (Alexander, 1984, 1985, 1986); some dealt with the potential of water resources, especially the mine ponds, for irrigation (Ihemegbulem, *et al.*, 1992; Phillips-Howard and Schoeneich, 1992); others discussed general rural marketing issues (Porter, 1992b) and more specific food marketing and urban food supply concerns (Porter, 1992a). Other useful reports that examine various farming issues were presented at the closing seminar of Phase II (e.g. Dabi, 1992; Alexander, 1992; Phillips-Howard, 1992a, b).

The coupling of these reports with more recent research (Porter *et al.*, 2002) has provided evidence for the continued importance and expansion of DSIVP on the Jos Plateau. Vegetable gardening was already in evidence in the early 20th century because of the tin mining in the area that led to the development of a large expatriate community (Freund, 1981, as cited by Porter *et al.*, 2002). The process of expansion (beyond peri-urban areas around Jos to rural areas around 50km from the city) commenced with Nigeria's petroleum boom in the 1970s, as the growing urban and affluent population increased the demand for vegetable produce. This is interesting because it runs counter to the general decline in the agricultural sector across much of Nigeria in the same years (as there had been a shift away, even in popular consumption, from traditional staples to refined white flour, wheat bread, imported rice and other convenient imported foodstuffs) (Porter, 1992a). The increase in DSIVP on the Plateau was encouraged by the presence of a market, but it was also enhanced by the favourable climate, its central position in relation to the rest of Nigeria, its relatively high degree of accessibility by road, rail and air, and the recession in the tin mining industry, which freed up a considerable labour force (Adepetu, 1985). With the implementation of the Structural Adjustment Programme (SAP) in 1986, with the stated aim of achieving food self-sufficiency, food importation ceased abruptly. On the Plateau, this resulted in further expansion of farming activities, both as large-scale and smallholder production (Porter, 1992a), although Phillips-Howard and Kidd (1990) cautioned that there was evidence that, in some areas, farmers intensified production in existing farms before expanding to new areas. Intensification on the Jos Plateau has been viewed very favourably: Phillips-Howard and Lyon (1994) contend that, contrary to the view that agricultural intensification is a threat to soil fertility in Africa, around Jos intensification appears to have locally enhanced soil fertility. Since the 1990s, expansion has continued, markedly so along the paved road, but also wherever there is water available for irrigation (Porter *et al.*, 2002).

The great expansion of DSIVP is remarkable when the environmental, technical and economic constraints that farmers have to face are considered. The existence of a growing market for vegetable produce is obviously a strong driving force behind DSIVP, but it must not be forgotten that farmers were not always working in favourable conditions. One noteworthy achievement of the farmers was the development of a highly successful SFM strategy. Soils on the Plateau have low levels of plant nutrients and tend to be acidic; nitrogen and phosphorus deficiencies are common (Alexander, 1986). Tin mining exacerbated this problem and governmental agencies deemed large areas of degraded mine land as totally unsuitable for any agricultural purpose (Alexander and Kidd, 2000). Nevertheless, the presence of easily available water (in the form of mine ponds) meant that farmers went ahead to reclaim the land and, as Alexander's work on restored mine-land demonstrated (Alexander, 1984, 1992, 1996; Alexander and Kidd, 2000), they were able to successfully raise the fertility status of the soils.

The SFM strategy consists of a series of soil conditioning techniques, followed by treatment with a combination of inorganic and organic fertilisers (Phillips-Howard and Kidd, 1991). A very important component of this reclamation strategy is ash, and, as already mentioned in an earlier paragraph, farmers made the transition from using household refuse ash or cooking-fire ash to town refuse ash, probably in the late 1970s (Alexander, Pers. Comm., 2002). Hausa farmers are very confident in their ability to use any type of land for farming; Phillips-Howard and Kidd (1991) reported that farmers believed that, if there was fertiliser, all soils were the same. Hence, soil management mattered more than differences in soil type to crop production. The farmers think that ash application is critical, and one non-Hausa farmer, who was learning DSIVP from the Hausa farmers, explained during the thesis' fieldwork in 2000, that the Hausa farmers encouraged him to apply ash, saying that it would "*turn the soil to become normal*", and particularly his portion of mine land would "*never become good if you do not apply ash*". It is fascinating to see how the farmers have developed a complex yet successful SFM strategy by incorporating their traditional farming practices with novel inputs. As already described in Chapter 1, farmers learnt to use IFs from extension agents, but rather than replace organic amendments with them, they chose to combine them. Similarly, they adapted to changing circumstances by switching from household refuse ash to the large supply of urban waste ash, probably in response to a decreased availability of household refuse (because of DSIVP expansion) and an increased availability in motorised transport. Their flexibility explains, in part, why DSIVP has continued to expand: in times of difficulty they will seek alternatives. For example, when the Nigerian government had cut down on subsidies on IF in the 1990s (Porter *et al.*, 2002), the farmers relied more heavily on organic amendments, including town refuse ash.

2.4 INDIGENOUS KNOWLEDGE AND INDIGENOUS AGRICULTURAL PRACTICES

As already discussed in section 2.3, the research approach of phase two of the JPERDP was people-oriented, as it was acknowledged that any sensible and viable recommendation to further development had to take into consideration all constraints and available resources. This meant that not only were environmental and technical constraints important in the formulation of solutions to particular problems, but also information on local knowledge and socio-economic conditions was needed to determine the viability of a particular solution. This position slotted into a very popular debate on knowledge and development, which emerged in the late 1970s, and is being expanded and, very importantly, applied in development approaches today.

Scientists have often taken a critical view of local, indigenous knowledge. They have condemned it as 'primitive', 'unscientific' and 'wrong'; and they have set themselves the task of 'educating' rural people, using a transfer-of-technology (ToT) approach (Scoones and Thompson, 1994b). For many decades, the idea that local people could have something to contribute to development was not even contemplated. Indeed, in many settings today, the transfer-of-technology approach continues to dominate (Reij and Waters-Bayer, 2001a). In the late 1970s, this perspective was challenged, with a populist approach that viewed indigenous technical knowledge (ITK) as a valuable, untapped source, and believed that it had to be 'incorporated' into formal research extension and practices in order to make agricultural development more sustainable (Scoones and Thompson, 1994a). Although there were previous books that played major roles in introducing the debate, a key text is certainly "*Farmer First*" (Chambers *et al.* 1989). Farmers were no longer seen as ignorant and naïve: they were experimenters, who dynamically interacted with their environment, and who didn't passively adopt extensionists' fixed packages of technology, but adapted them to their own circumstances. They maintained diversity, created new farming systems, applied technologies appropriately to different environments, designed new machinery and new methods of pest control or fertiliser application (Rhoades, 1989; Maurya, 1989). Apparently inefficient resource and space management (in mixed cropping) turned out to be a rational and effective design (Gupta, 1989).

The new paradigm 'Farmer First' was successful in challenging the conventional modernisation paradigm of 'ToT', but the debate moved forward into a "*Beyond Farmer First*" (Scoones and Thompson, 1994b) approach with the realisation that 'Farmer First' populism lacked a certain analytical depth. Indeed, as the authors of "*Farmer First*" themselves expressed it: "*This book is not a final statement, but part of a process*" (Chambers *et al.*, 1989, p. xv). The 'Farmer First' advocates believed that among farmers (or communities) there existed common goals, interests and power and, thus, they advocated farmer consensus solutions to identified problems. The perceived role(s) of the researcher (the 'outsider') was to act as an *invisible* information collector, a documenter of rural people's knowledge (RPK), a planner of interventions, or a manager of implementations (and, more recently, as a facilitator, catalyst or initiator). The research style follows a 'positivist' agenda and thus entails a hard-systems approach, focusing on discreet elements and hierarchical patterns. Thus, the farmers (the 'insiders') at best were expected to be reactive respondents or passive participants. The 'Beyond Farmer First' approach embraced the major tenets of active participation, empowerment and poverty alleviation of the populist approach but brought around new theoretical considerations, methodological challenges and institutional innovations. The 'Beyond Farmer First' proponents acknowledge that there are differentiated interests, goals, power and access to resources between actors and networks of actors. There is recognition that knowledge is a social process and knowledge systems must be viewed not as single stock or stores but in terms of the many actors and networks of actors through which technical and social information are communicated and negotiated. Knowledge cannot be easily extracted from the web of processes that originated it: it is fragmentary, unevenly distributed, and tends to emerge because of discontinuous interactions between the actors and the networks of actors. Thus, there is need for negotiation and conflict mediation between different interest groups; process learning and planning with dynamic and adaptive implementation of negotiated outcomes; collaborative work requiring dialogue, negotiation and empowerment. Clearly then, the role of the 'outsider' takes on a dimension of facilitator, initiator, catalyst, and he is definitely a *visible* actor in process learning and action. The 'insider' becomes a creative investigator and analyst, an active participant, and there is a move to post-positivist, soft-systems learning and action research (Scoones and Thompson, 1994b).

The understanding of 'indigenous' knowledge is, therefore, complicated by many factors. It is obvious that different spheres in society will have access to differing knowledge, and there is the added complication that information may be concealed. For example, the relations between different social groups may lead to only the opinion of the powerful 'authority' being voiced: the discourses of the weak are fragmented or left unsaid (the 'hidden transcript') (Scoones and Thompson, 1994b). In other cases, knowledge may be wilfully withheld because of distrust, or because it is a 'family secret', something to be shared only in particular circumstances (Pottier, 1994). In other instances, information cannot be regarded uncritically because it is influenced by certain expectations, as Phillips-Howard and Kidd (1990) found when reporting on the role of farmer knowledge systems in solving the problems they had to deal with. Their opinion was that the major problems identified by the farmers were not necessarily objective because of the possible influence of the '*kawo*' (bring) mentality (i.e. the farmers gave high ranking not to the largest problems, but to the problems that they perceived as solvable by the 'outsiders'). The quality of the information collected is also dependent on the understanding of the outsider. For example, sometimes when tested scientifically farmer classification systems are supported by scientific criteria and, thus, they can easily be understood by the scientific community. In other situations, the classifications are *functional* classifications and use different criteria and are more difficult for the outsider to relate to. In Zambia, farmers create their soil classifications by looking at topsoil properties, whereas scientists are interested in the subsoil chemical parameters. This means farmers can identify one soil type, where scientists see more than one (because the topsoil is the same, but not the subsoil) and *vice versa* (Sikana, 1994). The mismatch between the two classifications certainly does not invalidate the farmers' classification but it highlights that there is need to reflect on questions such as those raised by Salas (1994): can Western science understand local (in this case Andean) knowledge? As knowledge is linked to cultural interpretation and knowledge is interpretation of interpretations, can western science get inside the system of meaning of Andean knowledge without distorting it? Whose limitations are causing conflict? Does Western knowledge have its own epistemological limitations or is Andean knowledge limited by its cultural setting? Could these world views be totally different and incompatible?

The 'Beyond Farmer First' debate has provided a very rich intellectual setting for the discussions on 'farmer participatory research'. Indeed the notion of participation has obtained a wide following. Yet, the question remains, how does this translate into practice? Scoones and Thompson (1994b) highlighted that even those populists who saw themselves as catalysts or facilitators, continued as information collectors, documenters of rural people's knowledge (RPK), designers, planners, managers and evaluators of research or development initiatives. The gap between the intellectual discussion and the reality of field research has been discussed by Okali *et al.* (1994). The authors emphasised that, despite the rhetoric of participation, there is little sense of negotiation in many farmer participatory research programmes and, in fact, these cases looked strikingly similar to on-farm trials.

The notions of participation and farmer innovation are very popular in current agricultural research. For example, a recent e-conference on urban agriculture (February 2002 at www.ruaf.org) addressed (among several themes) participatory technology development. It was clear from the discussions that many researchers recognise the importance of identifying farmer innovators and supporting farmer experimentation. Yet, there is still a long way to go: although there are increasingly more experiences in supporting farmer experimentation and building on local initiatives to solve problems, they remain marginal to mainstream research, which continues using the ToT model. Nevertheless, the successes of some new projects prove that it is necessary and possible to bring about the institutional change needed to facilitate the improvement of agricultural systems through the empowerment of the farmers themselves. An example of a very successful project is provided by the second phase of the action-research programme of Indigenous Soil and Water Conservation (ISWC 2), which took place in seven Anglophone and Francophone African countries, and its sister programme Promoting Farmer Innovation in Rainfed Agriculture (PFI), which has been operating in East Africa. The experiences of the project have been documented by Reij and Waters-Bayer (2001a). The programme consisted of ten components:

1. To train scientists and extension agents from these countries in Participatory Rural Appraisal (PRA) and Participatory Technology Development (PTD) techniques.
2. To identify and verify farmer innovators.
3. To discover more about the characteristics of innovators and their innovations, as very little is documented about farmer innovation in Africa.
4. To set up a monitoring and evaluation system to show whether or not the programmes had been successful in enhancing the capacity of farmers to experiment and innovate.
5. Organise exchange visits and study tours for innovators so they could exchange information and experience.

6. Promote a programme of farmer evaluation of local innovations so as to embed individual experimentation within the wider social process.
7. Stimulate and support joint experimentation by scientists, extensionists and farmers.
8. Encourage farmer-to-farmer dissemination of innovations.
9. To raise awareness about farmer innovation and lobby for policy change.
10. To start taking the first steps towards the institutionalisation of the farmer innovation approach (Reij and Waters-Bayer, 2001b).

The ISWC 2 and PFI programmes have had many lessons to share. They have successfully raised the awareness of scientists/extension agents to the innovativeness of the farmers, distancing them from the ToT approach. They have identified over 1000 innovators in the course of the 3-year programme and, in many cases, have managed to promote the sharing of experiences amongst innovators and amongst innovators and their communities. They have commenced the process towards institutionalising the farmer innovation approach. An important lesson was that although the original assumption had been that joint experimentation by farmers, extension agents and scientists would commence at the end of Year 1, the entire process actually required a longer time. In fact, in most countries joint experimentation did not begin until Year 3 (Reij and Waters-Bayer, 2001b). The requirement for extended interaction between researchers and farmers, before there is a move towards participatory experimentation, has been noted by other sources (Okali *et al.*, 1994; Prain and de Zeeuw, 2002), and it implies that the implementation of short-term participatory projects will not be successful. There is need for time to build up a climate of mutual trust and respect that will facilitate joint experimentation. Furthermore, even when the atmosphere is conducive to collaborative work, there can be conflict between the researchers' approach and the farmers' approach. A good example comes from Ethiopia, where researchers found that it was very difficult to standardise trials because farmers wanted flexibility on the timing of sowing, weeding, etc., as they wanted to react to local climatic conditions (Miruts and Abay, 2001).

2.5 SUSTAINABLE AGRICULTURE

Notions of sustainability are incorporated into much of today's agricultural development research. The opening chapter of FAO's assessment of the patterns of world agriculture towards 2010 states that one major issue in world food and agriculture is: "*Safeguarding the productive potential and broader environmental functions of agricultural resources for future generations, the very essence of sustainability, while satisfying food and other needs*" (Alexandratos, 1995, p. 1). Quotes like this are widespread in the literature and yet sustainability remains an elusive concept. Sustainability is somehow understood by use of indicators, but the problem is that these indicators will vary according to the objectives, applications and targets of the organisations that develop them (Diaz-Chavez and Wathern, 2001). Sustainable agriculture, which is a smaller component of the 'sustainable development' concept, similarly suffers from the lack of a common definition. It has been defined in innumerable ways by various authors, using many different parameters. Although there is a general consensus about the problems that affect conventional agriculture and the need for a new approach, there are significant differences between the alternatives (e.g. integrated pest management, integrated crop management, low input agriculture, low input sustainable agriculture, agro-ecology, biodynamic farming, organic farming, etc.) developed in order to approach sustainability (Rigby and Cáceres, 2001). Indeed, the determination of sustainability will depend on what type of sustainability is in view (environmental, technical, social or economic), what level of sustainability is envisaged (high, moderate or marginal), and what time-scale is being used (Olofin, 1996). Some authors argue that it is only in retrospect that truly sustainable techniques can be identified as the recognition of a currently sustainable technology, which is based on hypotheses regarding the sustainable management of natural resources, maintaining their productive capacity through time, would require constant monitoring and re-evaluation (Rigby and Cáceres, 2001).

Hansen (1996) offers a good review of the various interpretations of agricultural sustainability. He identifies two schools of thought: one that identifies sustainability as an approach to agriculture that has as a goal to motivate adherence to sustainable ideologies and practices; the other is a system-describing concept that interprets sustainability as an ability to fulfil a set of goals or an ability to continue. He acknowledges that the first interpretation of sustainability as an approach to agriculture has been very useful to motivate change but ultimately is unsuitable to guide change because it may either lead to errors of ignoring approaches that enhance sustainability (because they have been classified as unsustainable, 'conventional' agriculture) or of promoting approaches that threaten sustainability (because they are considered 'alternative' agriculture). In short, if sustainability is interpreted as a philosophy or a set of strategies, it impedes the evaluation mechanism to recognise errors and improve the approaches. He also criticises the second way of viewing sustainability as a property of agriculture. If sustainability is seen as an ability to satisfy certain goals, the problem of defining which goals are important is encountered. Goal specification and ranking is highly subjective and is linked to the goals and values of the author of the definition rather than to the agricultural system. He sees the interpretation of sustainability as an ability to continue as a valid approach, as it is consistent with the literal English usage of the word 'sustain' and its derivatives, and because it can suggest criteria for characterising sustainability. He cautions that this potential usefulness has been limited by inadequacy of current approaches to characterising sustainability. He concludes his paper by suggesting that the characterisation of sustainability should be a systems approach comprising *literal*, *system-oriented*, *quantitative*, *predictive*, *stochastic* and *diagnostic* elements (Hansen, 1996, p. 138).

It is emphasised that it is beyond the purpose of this thesis to enter the debate surrounding the controversies over sustainability, or to advance a new definition. The author is inclined to agree with Rigby and Cáceres (2001), that a truly sustainable approach can only be identified in retrospect. And yet, for want of a better expression, the thesis does employ the word sustainability. It is used loosely, in the sense of whether soil nutrient levels are being maintained and whether this has the potential to continue. This involves looking at what effects farming practices have had on nutrient status in the long term (i.e. from the time that soils were brought under cultivation), and in the short term (i.e. whether farmers are supplying sufficient nutrients to the crops over the course of one season, without depleting soil nutrient levels). This information can be coupled with information on changing socio-economic conditions, so as to predict whether farmers are likely to be able to maintain soil nutrient status in the near future. It is readily acknowledged that if the purpose of the thesis were to advance a new definition of sustainability, this approach would be insufficient because it largely ignores social, economic and other environmental aspects; however, it is re-emphasised that the aim of the thesis was to look at soil nutrient 'sustainability' only.

2.6 THE NEED FOR FURTHER RESEARCH

The previous sections have reviewed various themes that are connected to this thesis. A few key facts emerge from the information so far:

1. Since the 1990s, DSIVP on the Jos Plateau has continued its dramatic expansion, developing mainly along paved roads, but also wherever there is water available for irrigation (Porter *et al.*, 2002).
2. Research carried out in the early 1990s provided evidence for the improvement of soil fertility through agricultural activity. Phillips-Howard and Lyon (1994) made the case that contrary to the widespread view that agricultural intensification was a threat to soil fertility, on the Jos Plateau intensification had actually resulted in the apparent enhancement of soil fertility. This was done in spite of the relative inaccessibility of IF, as a result of the detailed indigenous knowledge on SFM strategies. Indeed, soil analyses carried out by Alexander (1996) showed that local farmers had devised a highly successful strategy for reclaiming degraded mine land that consisted of mixing IF, manure and urban waste ash.
3. The town refuse ash appeared to be a critical element in the reclamation strategy for degraded mine land. It was interesting to note that although household refuse/farm waste/manure/ wood-fire cooking ashes had always been part of the local SFM strategies,

with the increased urbanisation (which generates a lot of waste) and the increased transport availability, farmers had made the transition to using town refuse ash.

These points lead to the formulation of a number of research issues. The rapid expansion of DSIVP is cause for concern because the resulting changing socio-economic conditions can rapidly modify farmer practices, which, in turn, will affect the stability of the system. Indeed, recent work indicates that the situation may be changing and from their analysis Porter *et al.* (2002, p. 8-9) conclude that: "*In total, the environmental picture suggests a situation of fragility. For the moment farmers are continuing to achieve high and profitable levels of cropping, but without paying much heed to sustainability issues. Water shortages and the ever growing demand for fertiliser reported above are early warning signs which should not be ignored*". So, the question is, given the dramatic expansion of DSIVP, what is the current situation on SFM? Has this changed in respect to the past and what have been the effects from a purely soil fertility perspective? Do Phillips-Howard and Lyon (1994) and Alexander's (1996) conclusions still hold today? What are the prospects for the near and medium-term future?

The use of urban waste ash ties in with these queries. Although the practice of using town refuse ash has been documented several times (Alexander, 1986, 1996; Phillips-Howard and Kidd, 1991), very little is known about the mode of action of this material. Phillips-Howard and Kidd (1991) collected some information on the farmers' characterisation of the properties and function of ash (during their investigation on general knowledge and management of soil fertility), whilst Alexander (Pers. Comm., 1999) had found that the ash had a high pH, which helped explain why the farmers valued the material (it would neutralise soil acidity and increase availability of some bound nutrients). Given the importance of ash in the farmers' SFM strategy, it is necessary to gather much more detailed information on this material. For example, what are the chemical properties of town refuse ash produced in and around Jos? Can it be considered a fairly homogeneous substance? What are the farmers' reasons for integrating it into SFM practices? What are its possible modes of action as a soil amendment? What potential health hazards are attached to using this material?

The full understanding of the problem of soil fertility management, though, is not complete without an understanding of general farming problems. If farmers are under pressure because of short-term, *immediate* problems, they may not be in a position to consider SFM because it is a long-term issue. Hence, any recommendations issuing from the thesis would largely be ignored, unless critical problems were removed first.

This piece of research, consequently, sets out to shed light on a few of these issues by fulfilling the aims and objectives set out in the next section.

2.7 AIMS AND OBJECTIVES

This thesis has four major aims:

1. To identify critical characteristics of present soil fertility management practices (i.e. the use of inorganic fertilisers, manure and (town refuse) ash) and acquire an understanding of the rationale behind them and identify the direction of future practices.

2. To gain insights into the sustainability (in terms of nutrient supply) of the local agricultural system around Jos.

3. To provide an appreciation of the role played by urban refuse ash and highlight the risks attached to its use.

4. To place soil fertility management into the broader context of farming problems.

In order to achieve these aims, the following objectives have been identified:

I. Describe current soil fertility management practices and suggest future trends.

II. Collect data on the soil nutrient and heavy metal status from case study farms and identify possible deficiencies or toxicities.

III. Determine the changes in nutrient status of the farmed soil in respect to the uncultivated soil as a result of farming practices in the case study farms (long term effects).

IV. Determine the changes in nutrient status in each case study farm over the course of one farming season to check whether farmers are meeting crop demands (short-term effects).

V. Identify whether there is any evidence of heavy metal accumulation in the soil or in the food chain.

VI. Examine the chemical characteristics of the refuse ash and determine whether it can be considered a homogeneous material.

VII. Investigate farming problems as perceived by the farmers and by governmental organisations.

3 THE CHARACTERISTICS OF THE STUDY AREA

3.1 LOCATION

The Jos Plateau (Figure 3-1 and Figure 3-2) is a highland area that rises from the plains of central and northern Nigeria between 8°55N and 10°11N and 8°21E and 9°30E (Phillips-Howard, 1992a). The Plateau surface occupies an area of some 8600km^2 (Alford *et al.*, 1979) lying at about 1,200mamsl and rises above 1400mamsl to the south of Barakin Ladi and the east of Jos (Phillips-Howard, 1992a).

The thesis was mainly located in one farming area known as Delimi Langalanga. This area has also been variously referred to by other researchers as Delimi or Delimi Yelwa (from the village where most of the farmers live), (e.g. Phillips-Howard, 1992b). The site is located along the Delimi River, to the north of Jos and extends northwards from the University of Jos Senior Staff Quarters (Figure 3-1). A second site at Rayfield, an extensive area that lies to the east of the Jos-Bukuru Road (Figure 3-1), was visited on a number of occasions. Two other sites were visited for the purpose of conducting a survey and these were the town of Barakin Ladi (Figure 3-1) and the small village of Korot, which is not marked on the map but is located along the river Korot in a former tin mining area to the east of the Bukuru-Barakin Ladi road, shortly after the turn-off to Old Jema'a (Figure 3-2).

3.2 GEOLOGY AND SOILS

The Plateau is characterised by three main rock types: the Basement Complex rocks (which include Older Granites and metamorphic rocks) that underlie more than half the Plateau; the Younger Granites and the Older and Newer Basalts (Phillips-Howard, 1992a; Alford *et al.*, 1979). The Post-Older Basalt Unconsolidated Deposits are particularly important as they form the parent material of many soils on the Jos Plateau. They are divided into the Rayfield, Bokkos and Bisichi Deposits and Ngell Alluvium (Alford *et al.*, 1979).

It is likely that the soils on the Plateau are relatively young. The majority probably originate no earlier than the mid-Quaternary. Four soil associations have been identified on the Plateau (Alexander, 1986):

1) *Soils on Unconsolidated Deposits.* On interfluves these soils are commonly associated with rock outcrops or lateritic ironpans. They grade down slope into well to imperfectly drained, strongly mottled soils and can frequently comprise a layer of yellow aeolian loam. They comprise gleyic, ferralic and chromic Cambisols.

2) *Soils on Newer Basalt.* Those that occur on steeper slopes and footslopes of volcanic cones are deep, well drained and well structured. On shallow slopes the soils vary in depth and are strongly mottled. They tend to be more base rich than soils that have developed on unconsolidated deposits or granite. They comprise Lithosols, pellic Vertisols, dystric Gleysols and gleyic, ferralic, chromic and eutric Cambisols.

3) *Soils on Granite.* These soils are almost invariably coarse textured, well drained and shallow. They comprise Lithosols and dystric Cambisols.

4) *Soils on the Basement Complex.* These soils are very similar to those developed on unconsolidated deposits but the principal difference is that they are usually only 1.0 to 1.5m deep over decomposing bedrock. They comprise Lithosols, gleyic and ferric Luvisols, ferralic, chromic and eutric Cambisols.

The Jos-Barakin Ladi area (Figure 3-3), which comprises the thesis' study locations, is an extensive area in the north and in the centre of the Plateau that is developed on Rayfield Deposits overlying Younger Granite or Basement Complex (Alford *et al.*, 1979). The soils characterising this area typically belong to soil associations developed on unconsolidated deposits (soils typical of the plains) but there are also cultivable valley land soils. These soils are traditionally known as *fadama* soils. True *fadama* soils may be gleyic Cambisols and they tend to be rich in organic matter, highly fertile, well-structured and quite permeable in the dry season, and hence they are potentially very productive. There may also be ferralic Cambisols (which are imperfectly drained, poorer in organic matter and inherently less fertile) and soils typical of the plains (Phillips-Howard, 1992a).

3.3 CLIMATE

The climate of the Plateau differs markedly from that of the surrounding plains. The seasonal migration of the Inter-Tropical Convergence Zone (ITCZ) governs the sequence of three seasons: a cool dry season (October to February), a hot season (March, April) and a wet season (May to September) (Alford *et al.*, 1979). The cool months are characterised by a dusty and dry north easterly air flow which brings clear skies and cool or cold night temperatures, variable day time temperatures, minimal rainfall and dust haze (the *Harmattan*). As the ITCZ moves in from the south, the north easterly air flow weakens and consequently both humidity and temperature start to rise, which causes the onset of the rainy season, during which both temperatures and humidity decrease slightly (Alexander, 1986). Mean monthly temperatures range from 20 to 24°C (Phillips-Howard, 1992a). The average temperature and rainfall across the whole of the Jos Plateau can be seen in Figure 3-4. The relief of the Plateau and the direction of the air flow mean that rainfall is far from being uniform. The highest totals occur on the hilly western margin (particularly the south-western margin) and the lowest on the eastern plains of Panyam and Pankshin (Alford *et al.*, 1979).

Jos, at an altitude of 1,285m has a mean annual temperature of 21.8°C, ranging from 20.2°C to 24.3°C (mean monthly temperatures). Mean annual rainfall is 1,413mm and the rainy months (May to September) are each characterised by approximately 200 to 300mm (the peak rainfall period is July, with 321mm). Outside of these months rainfall drops off sharply (Alford *et al.*, 1979).

3.4 HYDROLOGY AND OTHER WATER SOURCES

The Jos Plateau is considered the 'hydrological centre' of the country. The drainage is radial and the watersheds of three major river systems of the country come together at a point near Rayfield (Figure 3-5). The Delimi River drains to Lake Chad; the Gongola, Wase, Shemankar, Ankwe and Mada Rivers drain into the Benue, and the Kaduna river into the Niger (Alford *et al.*, 1979).

Phillips-Howard and Schoeneich (1992) estimated that on the Plateau there were 629,800ha of irrigable land (i.e. 77% of the total area) and that there were sufficient water resources (comprising groundwater and surface water) to irrigate 96% of this land. However, they stated that, at that time, the local labour supply would only be sufficient to cultivated 13% of the irrigable land. Nevertheless, they believed that, providing that demand for irrigated agricultural produce continued, and profitability of dry-season farming continued to increase, all of the 96% of potentially irrigable land would eventually be brought under irrigated agriculture.

Mine ponds, which were left over by the Plateau's legacy of tin mining activities (Figure 3-6), provide a particularly valuable water resource, for agricultural, industrial, domestic and recreational purposes (Alexander, 1985). The tin mining affected some 325km^2 of land, most of which lies on the Jos-Bukuru-Ropp axis, leaving a derelict landscape of steep-sided mounds and over 600 groundwater-fed mine ponds and lakes (Alexander, 1985). Patterson's (1986) study of the mine ponds showed that the water was highly suitable for irrigation, as it has none of the toxicity problems usually associated with irrigation and lacks dissolved solids that can cause problems of high soil salinity. Later work showed that it was likely that most of these dams were in quite good condition and could be repaired to provide irrigation water for an estimated 1540ha of land (Schoeneich and Ihemegbulem, 1992).

Figure 3-1: The study area on the Jos Plateau

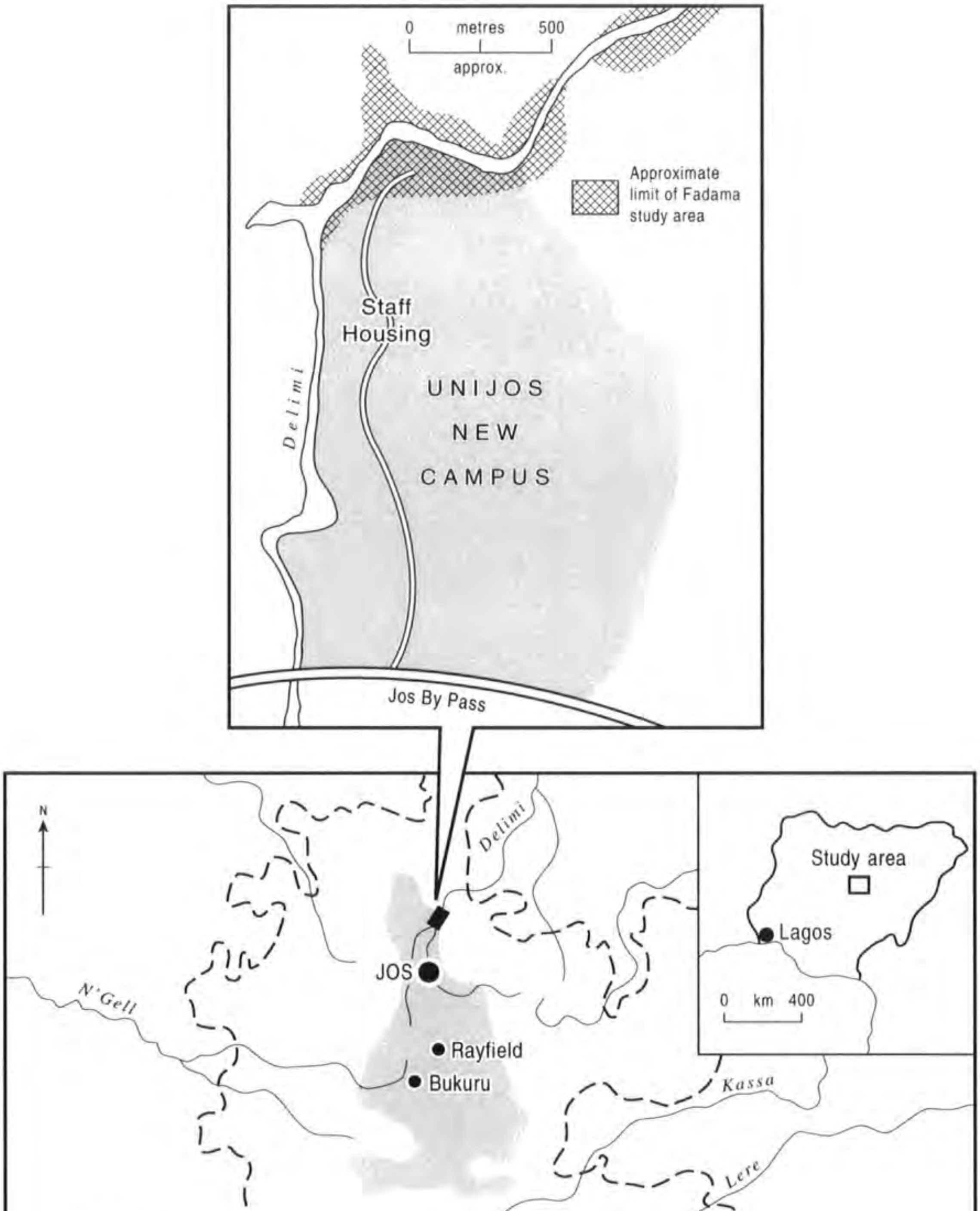


Figure 3-2: The Jos Plateau (after Alford *et al.*, 1979)

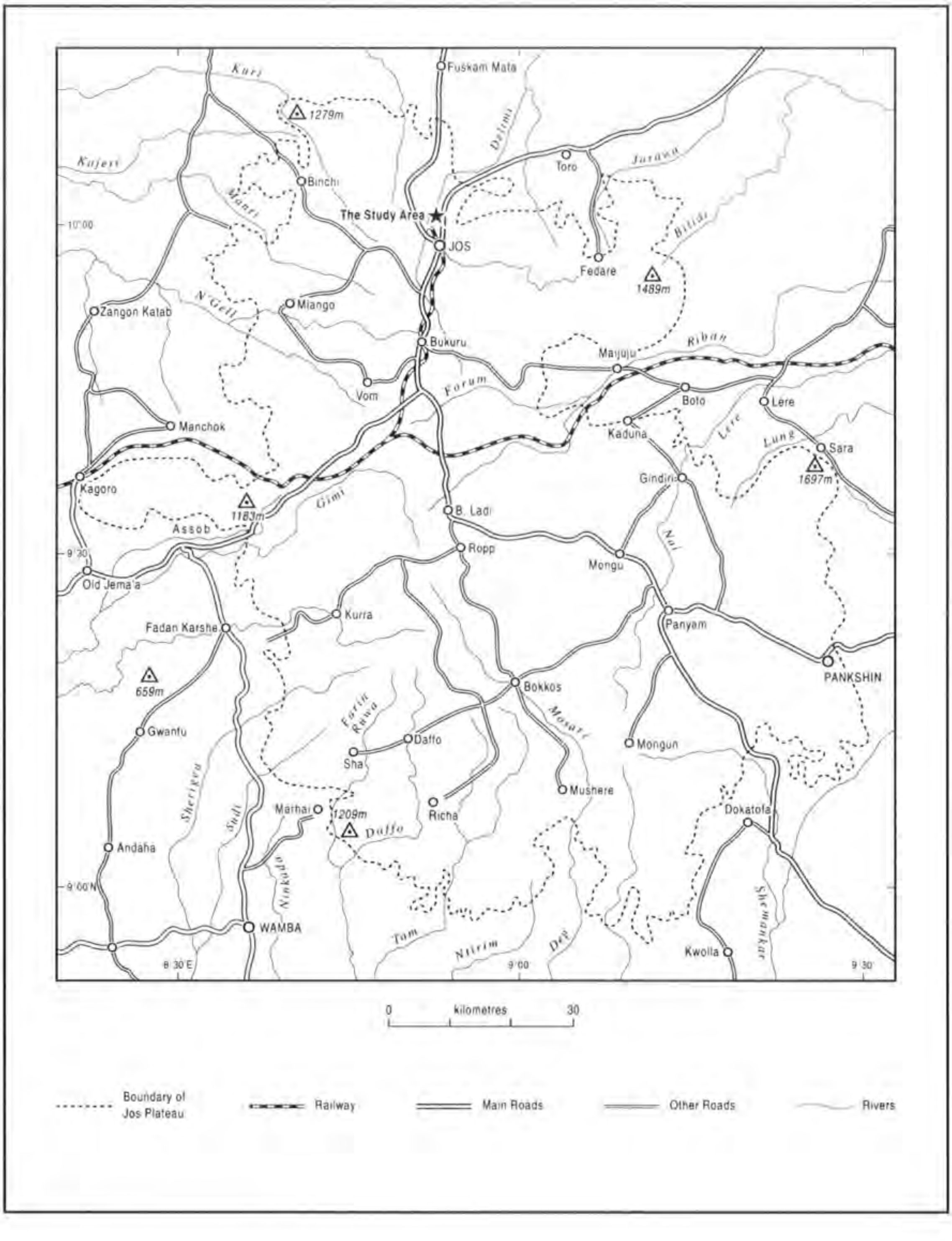


Figure 3-3: Physiography of the Jos Plateau (after Alford *et al.*, 1979)

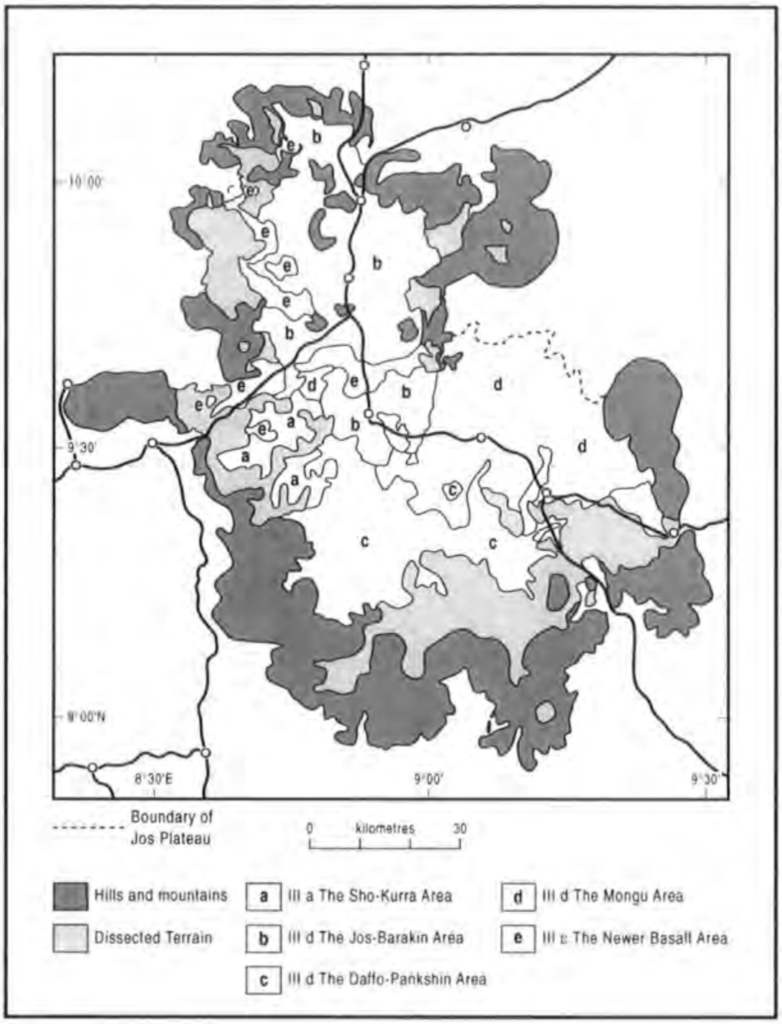


Figure 3-4: Temperature (°C) and rainfall (mm month^{-1})on the Jos Plateau (after Alford *et al.*, 1979)

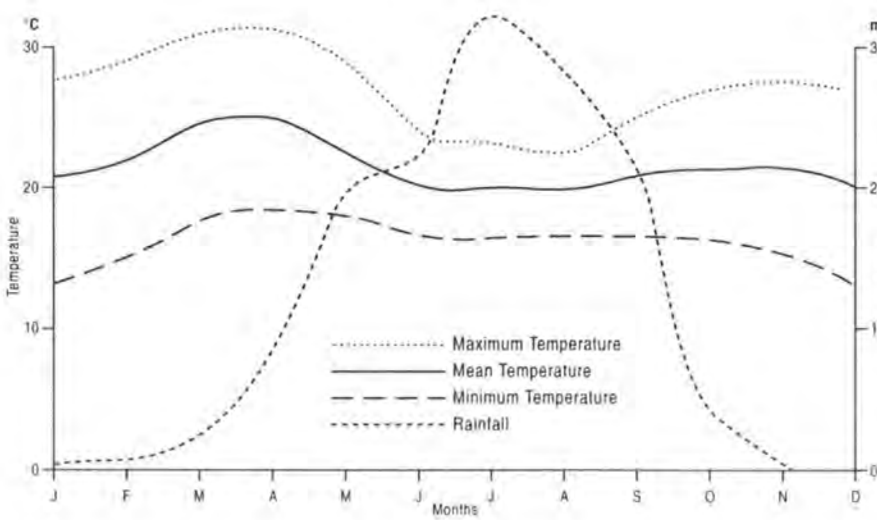


Figure 3-5: Drainage on the Jos Plateau (after Alford *et al.*, 1979)

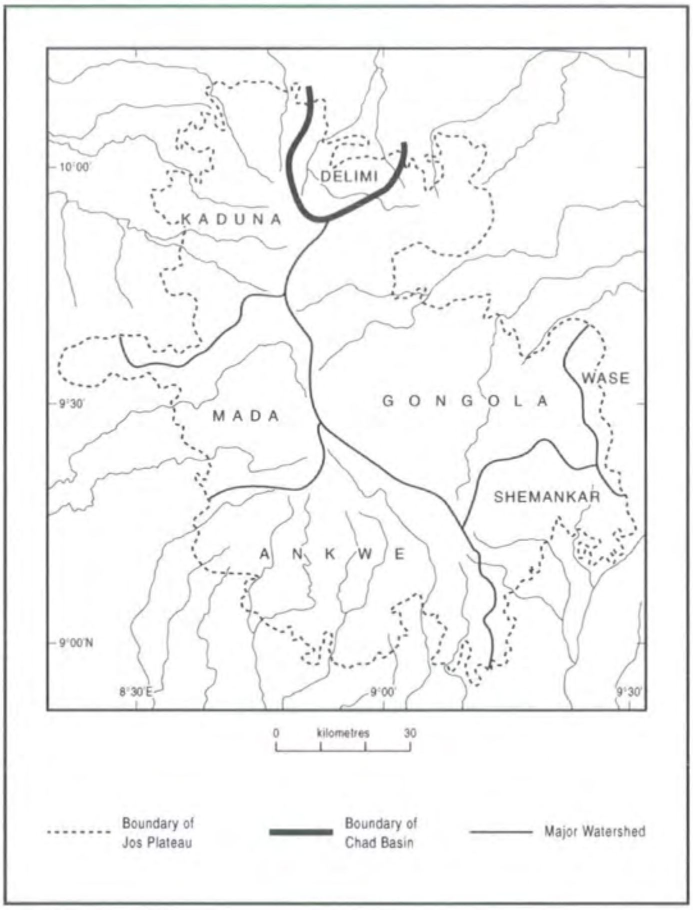


Figure 3-6: Clockwise from top left: mine ponds in the Rayfield area, a Rayfield farm with mine spoil heaps in the background, a mine pond in Barakin Ladi used for watering cattle, a steep-sided mine pond.

3.5 THE FARMING POPULATION

Over the course of the years, the Jos Plateau (and in particular the town of Jos) has attracted many people from all over Nigeria to come and settle. The three major indigenous groups are the Berom, Anuguta and Afisare; the three major settler groups are the Hausa-Fulani, the Igbo and the Yoruba; in addition to these there are over 150 minority ethnic groups from Plateau and Nassarawa States, various southern Kaduna groups, and other ethnic groups from the South (Danfulani and Fwatshak, 2002). The Hausa settlers were responsible for the introduction of dry season farming (Phillips-Howard and Lyon, 1994), and for many decades they predominated in this activity, hiring land from the indigenous Birom, to produce vegetables, which were marketed by themselves or by their families. In time, though, more and more Birom took an interest in farming and started learning the necessary skills from the Hausa farmers. This resulted in them claiming their land back from the Hausa, so much so, that in some areas, Hausa farmers, who always controlled a farm of their own, are reduced to working as labourers for the Birom. This has resulted in ethnic tensions (Porter *et al.*, 2002)[1]. This development is particularly true for large farming areas to the south of Jos, although in the peri-urban fringes of Jos, the Hausa still outnumber the other groups. For example, in Delimi and Rayfield respectively, 73% and 78% are Hausa, 11.5% and 10% are Fulani, 4% and 0% are Anaguta, 2% and 8% are Birom and the remainder come from minority groups (data obtained from survey described in 4.7.1).

In Delimi, all farmers are male and almost all are Muslim (96%); the average age is 40; 12% of farmers are single (most being under the age of 30), 44% are married with one wife, 31% with two, and the remainder (13%) with three. There is, unsurprisingly, a tendency for older farmers to be married to more wives. Mean number of children is 5.8. About half of the farmers have received no education (48%) whilst 27% have received Koranic education and the remainder (25%) Western education (primary or secondary); and about half (48%) are occupied in a secondary activity, mainly trading. On average, farmers have worked in the Delimi location 9.6 years (ranging from 1 to about 25 years), but have been independent market gardeners for about 20 years. The majority of farmers hire their land (71.2%), the others are owners through purchase (15.4%) or inheritance (11.5%), and the remainder is pledged land. In Rayfield, all farmers are male, and most are Muslim (91%); the average age is 44; only 4% are single, the rest being married to one (39%), two (41%) or three (16%) wives. Mean number of children is 6.3. A high proportion of farmers have received no education at all (70%), 10% have received Koranic education and the remainder Western education; 49% have a secondary occupation, which is mainly trading. On average farmers have worked the Rayfield site 8.9 years (ranging from 2 to 32), but have been independent market gardeners for 16 years. The vast majority rent

[1] The ethnic tension surrounding access to land and trade was probably a very strong contributing factor to the riots that occurred in Jos in September 2001 (which were in fact publicised as religious conflict) (Porter *et al.*, 2002; Danfulani and Fwatshak, 2002).

Towards the end of the rainy season the farmers start clearing the land from the dense brush that covered it during the rains. This is labour-intensive and frequently farmers need to hire people to help them clear the land. After clearing, the soil is broken up and turned over with a large hoe and the farm is prepared by constructing a network of channels and subplots for irrigation purposes (see 4.2.6). While the land is being prepared, the farmers also create a seed nursery. Once the seeds have germinated, the farmer will transplant the seedlings to the land he has prepared. After 10-12 days during which the seedlings are watered, weeding is carried out using a small hoe, the loosened soil is allowed to 'rest', then the farmer applies the first round of IF by broadcasting and waters the plot immediately afterwards. The soil is allowed to 'rest' again, and in the ensuing weeks it is watered and weeded. Just before the second round of IF the soil is weeded and hoed. A variable amount of time will pass between the first and the second fertilisation round: usually it will be one to two weeks. Often, in the evening of the second IF application (which is by placement to avoid damaging the crops), after the farm has been watered, ash will be applied. The farmer scoops the ash with his hands and throws it in such a way that the soil and the crops are covered with a thin dusting of ash. The process of 'resting', watering and weeding is repeated. A third application of either ash or IF can follow (after a variable amount of time, between a week and 20 days) and then the crops are left to grow until they are ready for harvest (mid-season harvest, in December/January). Watering frequency varies amongst farms, depending on soil type. Survey work (see 4.7.1) revealed that 63% of farmers water twice a week, 29% three times a week. The remainder stated that they irrigated once, two to three times or four times. The fertiliser applications vary amongst farmers: some will apply two or three rounds of IF only; others will apply IF, then ash, then IF; others still will apply two rounds of IF, followed by a third round of IF and ash on the same day; or maybe two rounds of IF and after a delay an application of ash. In the second half of the season the process is similar, but usually the farmer will limit himself to two IF applications and it is very rare that he will apply ash. A very few farmers may apply manure too (but it is not common), perhaps in combination with ash.

The amount of IF applied will depend on the soil type and also on the type of crops being grown. If farmers are planting a slow-maturing crop (tomato, cabbage, carrot) they will need to apply quite a lot of IF, compared to what a fast-maturing crop (spinach and lettuce) will require. The variety of crops grown in the farming area and the percentage of farmers growing each type are displayed in Table 3-1 (data obtained from the collaborative survey described in 4.7.1).

Table 3-1: Percentage of farmers growing various crops

Crop	*% of farmers*	*Crop*	*% of farmers*
Lettuce *Lactuca sativa*	90.4	Sweet Pepper *Capsicum spp.*	11.5
Cabbage *Brassica oleracea* var. *capitata*	88.5	Celery *Apium graveolens*	9.6
Carrot *Daucus carota*	84.6	Chinese cabbage *Brassica rapa* var. *pekinensis*	5.8
Green-leaf	78.8	Cucumber *Cucumis sativus*	5.8
Tomato *Lycopersicon esculentum*	71.2	Cauliflower *Brassica oleracea* var. *botrytis*	1.9
Green beans *Phaseolus vulgaris*	48.1	Leeks *Allium ampeloprasum*	1.9
Beet root *Beta vulgaris*	42.3	Radish *Raphanus sativus*	1.9
Onion *Allium cepa*	38.5	Turnip *Brassica rapa*	1.9

It is usual for the farmers to practise inter-cropping in preference to mono-cropping, mixing a slow-maturing with a fast-maturing crop. The reasons for practising inter-cropping are diverse but the most common motive is economic, as explained by Phillips-Howard *et al.* (1990) who made an example of a very common combination green-leaf/lettuce/tomato. The purpose of this combination was to ensure a continuous flow of revenue throughout the season, as green-leaf matures quickly (25-30 days), lettuce matures shortly afterwards (about 40 days), whereas tomato requires a long time (three-four months) before it starts fruiting. The first two crops are grown to generate some cash so that the farmer can support himself and his family and continue tending the tomatoes.

The interviews on cropping patterns (see 4.7.2.3) supported Phillips-Howard *et al.* (1990)'s explanation that choice of crop combinations was driven primarily by economic reasons. Farmers emphasised that every crop develops best if planted on its own (because it had room to spread and develop) but given their constant need for capital they could not afford to mono-crop, except in small portions of land, when they wanted particularly large produce. Their cropping strategies were also influenced by other factors:

1) *Soil type.* Some soils are suitable for any crop, other soils support certain combinations better than others, other soils still are only suitable for one specific crop. For example one farmer explained that he could not grow tomatoes on soil that was 'heavy' and wet and could only plant lettuce.

2) *Environmental conditions* (other than soil type). Drainage and exposure to sunlight. A shaded area can support lettuce but not carrots or tomatoes.

3) *Competition for space.* It is important to combine crops that will not interfere with one another during growth (so slow-maturing crops such as carrots and cabbage cannot be

planted together as one would smother the other). Interference between crops that can be combined together can be minimised further by spatial separation (by planting on subplot ridges) or temporal separation (by delaying planting as much as possible).

4) *Optimal space utilisation.* Another reason for combining crops is to avoid wasting space. A slow-maturing crop will stay small for quite a long time, and the space between the plants can be occupied by a fast-maturing crop that will be harvested before interference becomes considerable. Other crops that require little space for expansion can be planted on the ridges around the edges of each subplot.

5) *Market prediction.* There is a tendency for farmers to plant the same crop at the same time, and the consequent over-production will cause prices to fall drastically. Some farmers try to diversify and predict what strategy will bring maximum profit. Some will plant a certain crop late and settle for a lower yield but a large profit because the produce is out of season. Others will leave crops in the ground if they can (this is possible with carrots, leeks and onions) until the price in the market is high enough.

6) *Specialisation.* Large-scale farmers may become specialists in a particular crop (tomatoes for example) and market in the large southern cities (e.g. Port Harcourt), but still plant other crops as an insurance against the failure of the main crop.

7) *Experimentation.* Farmers may plant unusual combinations or time planting differently to improve their chances at having the right crop at the right moment.

It is essential to bear in mind that the driving force behind DSIVP is financial. The Plateau farmers are engaged in vegetable production for commercial reasons, not for subsistence or food self-sufficiency. Although it is beyond the scope of this thesis to go into marketing strategies on the Jos Plateau in any great depth, it is, nevertheless, important to have an understanding of where the produce is being marketed, and how this has changed in relation to the past. For additional information, reference should be made to two surveys conducted in three districts to the south of Jos (Fan and Ropp districts in Barakin Ladi Local Government Council (LGC) and Riyom district in Riyom LGC) in 1991 (Porter, 1992b) and 2001 (Porter, 2001), where the changes in marketing strategies, in relation to the increase in DSIVP, have been studied in great detail.

In 1982, most farmers sold their produce locally, indeed many transactions occurred on the farm itself; few farmers sold their produce outside of Plateau State (5%) and those few who did were located in specific areas, i.e. Barakin Ladi and Riyom Hoss but not Delimi or Rayfield (Adepetu, 1985).

In 1991, these spatial differences in marketing strategies persisted but marketing outside Plateau State was on the rise. In Delimi, farmers continued to sell in Jos markets or directly on the farm, although the latter form of trading had considerably decreased (Phillips-Howard *et al.*, 1990). In Barakin Ladi LGC, farmers were more flexible and depending on what would bring the most profit, produce could be sold on the farm, in local markets or directly in other States' markets. Although produce moved mainly to markets within Nigeria (Lagos, Kano, Kaduna, Imo State), it was also moving to neighbouring countries, such as Chad and Niger (Porter, 1992a).

In 2001, vegetable production was clearly focussed on supplying markets outside of Plateau State: in southern Nigeria and probably in neighbouring countries too (either directly, to Niger and Chad, for example, or via the southern markets first) (Porter *et al.*, 2002). This was evident in Barakin Ladi and Riyom LGCs (Porter, 2001), and it is a critical development that also farmers in Delimi (13.5%), and to a lesser extent, Rayfield (4%), are now marketing produce directly in big cities such as Port Harcourt, Onitsha and Enugu (data obtained from the survey described in 4.7.1). It indicates that, from an economic standpoint, DSIVP is highly successful and growing.

3.7 WET SEASON FARMING

This thesis did not carry out any investigations during the wet season. However, it is useful to provide a brief description of farming activities in this period, as it has implications for soil fertility. The wet season is used predominantly for the production of staple food crops: maize, cassava, guinea corn, sweet potatoes, millet, groundnut and rice. A few farmers also continue with vegetable production, concentrating on beans, cabbage, carrots, beetroot, green pepper and a few other species. There are differences in production between Delimi Langalanga and Rayfield: the questionnaire survey (4.7.1) revealed that although most crops could be found in both areas, farmers in Rayfield were the only ones who frequently mentioned planting millet and groundnut. In any case, in both areas, maize is the dominant crop. However, not all dry season farmers continue farming during the wet season. In Delimi Langalanga, 50% of farmers cease their activity during the wet season (and usually take up full-time trading), the remainder continue farming on higher ground that is not subject to the river flooding. In Rayfield the situation is somewhat different. Only 16% of the farmers stop farming to take up full-time trading. The remainder continue farming, 85% remain on their land in Rayfield (which is not subject to flooding, as farmers irrigate from the mine ponds), whilst 15% return to farm in their native States (Kano or Jigawa) (data obtained from the survey described in 4.7.1).

4 FIELDWORK DATA COLLECTION, LABORATORY AND STATISTICAL ANALYSES

4.1 THE INTERDISCIPLINARY APPROACH

Chapters 2 and 3 have introduced the setting within which this thesis moves. Chapter 2 in particular has described in detail the purpose of the thesis, and, therefore, this next chapter describes the techniques that were employed to find answers to the aims and objectives listed in 2.7. As stated in Chapter 1, a critical aspect of this thesis is its interdisciplinary approach. As other authors There are three important points to be made about the experience of carrying out interdisciplinary research. The first is that the boundaries between aims becomes blurred, as the information required to satisfy one aim may actually spill over to another aim. The second is that the balance between the two (or more) discipline methodologies involved is not static and pre-determined. On the contrary, it is constantly shifting and changing, throughout the research experience. The third is that the process of negotiation between approaches does not cease after fieldwork, but is carried through to the write-up.

To give an example to explain the first point, aim 1 (social science) overlaps with aims 2 and 3 (primarily physical science). Throughout this chapter there is an attempt to link sections to aims (and objectives), but because of the overlap, this is not clear-cut. The information collected for aim 1 links to information collected separately for 2 and 3, and this contributes to a better understanding of both 2 and 3.

To understand the second point, a brief description of the process of moving from one discipline to another is useful. Originally, the thesis was designed primarily as a 'natural sciences' project with a channel of communication open towards the 'social' sciences. Fieldwork changed this balance, shifting the emphasis of the thesis towards a more central point. Although the thesis still favours a 'natural sciences' approach, the importance of the socio-economic aspects is very clear. The decision of how much time to spend on each avenue of enquiry is a constant process of negotiation, and the shortage of examples to follow and model oneself on, is, at the same time, obstructing and liberating. It is obstructing because the researchers carrying out inter-disciplinary research will almost certainly come from either a 'natural' or a 'social' sciences background, not both. As a consequence, 'natural' scientists may feel more comfortable within the boundaries of their own discipline, and not venture very far into the 'social' science aspects, and *vice versa*. The lack of established examples means that it is very difficult to overcome the worries of venturing onto 'unknown ground'. At the same time, this fact is liberating because the researchers have the space to explore, invent and define for themselves the methodology for the project. The fact that the researchers are forced to make decisions about what to try and for how long, gives them confidence to move between different techniques. Not every approach will be successful but the fact of having tried it out is, in any case, a contribution to this new area. The more tools the researchers experiment with, the more they will find available to them.

The third point, in a way, is a continuation of the second: the challenge of inter-disciplinarity does not stop after the fieldwork stage. Upon returning from the field, the researchers find that different types of data analysis need to be mastered. Perhaps, the most arduous task of all is the write-up. The 'natural' and the 'social' sciences are stylistically different. The language, the way of presenting information; the partitioning of the different sections, all differ. Which should be used? Should the thesis follow the style of the dominant discipline or should the styles be merged? If they should be merged, how can this be achieved in a harmonious fashion? In this particular thesis, 'natural' science was the dominant approach so, it seemed appropriate to adopt this style of language, structuring chapters and presenting results. Nevertheless, some alterations and unconventional features were necessary. For example, in this methodology chapter, one section is written in the first person, despite the fact that the rest of the thesis is in the third person, because it deals with the issue of forming personal relations with farmers. The 'discussion' chapters are the truly inter-disciplinary components because they blend and mix information from both sides, so that there is an alternation of factual, scientific information, and empirically-derived information.

Although the previous paragraphs have hinted at the inter-connectedness of the various methodologies, for simplicity, clarity, and ease of reference, the next sections have been roughly grouped as 'natural sciences' approach (sections 4.2 to 4.5) and 'social sciences' approach (remaining sections). This should not obscure the fact that they were carried out simultaneously, and that the results of one approach may be tied in with the other approach. In some instances the techniques utilised to gather socio-economic data were useful to finalise the exact methodology for the 'physical' component: the early interviews on SFM strategies (4.2.3) defined the choice of fieldwork area, the actual study farms and the decision of not interfering with the farmers' work (see 4.2.2, 4.2.5 and 4.2.4). Throughout the research activities, the two approaches were blended and balanced, so that at certain times soil, fertiliser or crop sampling were the predominant activity and at other moments it was interviews, questionnaire surveys or discussions with the farmers.

4.2 INVESTIGATING THE SUSTAINABILITY OF THE LOCAL FARMING SYSTEM

This section predominantly describes the way in which information was collected to address aim 2. This was achieved primarily by addressing objectives II, III, IV and V although, as discussed in 4.1, the information collected specifically for aim 1 has relevance to aim 2. Therefore, part of the information for objective I was combined with data generated within this section, in order to fully address aim 2. Similarly, data generated within this section (4.2.10.1) has been used to address some issues connected to aim 3.

As discussed in section 2.5, it is very difficult to define what a sustainable agricultural system is. In this project the term 'sustainability' was used loosely, in the sense of whether farmers were supplying the crops with sufficient nutrients, without depleting soil nutrient levels. This idea was examined in two dimensions: in the short term, by appraising whether farmers were supplying adequate amounts of nutrients over the course of one farming season; and in the long term, by comparing the properties of cultivated and uncultivated soils. A future dimension was added by integrating data on current soil nutrient status with information on probable future changes in SFM practices (collected in 4.7). A few farms were selected as case studies, as obviously the analysis could not be carried out for the whole farming system. Although the outcome of case studies cannot be rigorously extrapolated to the whole farming system, it can provide an indication of what may be happening more widely, particularly if it is combined with information on SFM practices across the study area. The next sections, then, will describe the process of choosing a research approach, the study area and the study farms, the sampling strategies and the measurements required. Although most of this section deals with the sustainability of the farming system, part of the data collected was needed to gain an understanding of the risk of heavy metal accumulation in the soil, attached to the practice of using urban waste ash.

4.2.1 Fieldwork period

Fieldwork was carried out during the dry-season. This period has a duration of approximately eight months (September to April) and is characterised for the most part by the Harmattan and absence of precipitation (see 3.3). The onset and end of the season are obviously variable because they depend on the climatic conditions characterising a particular year. The farming year for 2000/2001 commenced in early September, with a few farmers taking advantage of the late rains. The majority of farmers commenced work in October, and no farmers started work after November (even though clearing and preparation of the land is a continuous process that occurs throughout the season). The 1st of April witnessed the first rainfall but as the early showers were light and infrequent, another month and a half passed before farmers started collecting their last crops and abandoning the land[1].

[1] The majority of farmers cease their activities during the rainy season, but a few may continue farming on the upper embankments that are not subject to the Delimi flooding.

4.2.2 Choice of fieldwork area

The generalities of the study area have been fully addressed in Chapter 3. During the planning stage of the thesis, three peri-urban areas of Jos were identified as potential fieldwork areas: Delimi Langalanga (Unijos Permanent Site), Rayfield and Anglo-Jos. Of the three, Delimi (Figure 3-1) benefited by having been the focus of previous research, which would help embed the research in changes over time (Adepetu, 1985; Alexander, 1992, 1996; Phillips-Howard, 1992b; Phillips-Howard *et al.*, 1990, Phillips-Howard and Kidd, 1990, Phillips-Howard and Kidd, 1991). The first period of fieldwork was, in any case, employed in making a definite choice for the study site, and this was done by discussing the advantages and disadvantages of each site with knowledgeable local researchers and visiting each site. Finally, a meeting was arranged with the head of the farmers (*shugaba*)[2] of Delimi (through one of the researchers from the local University who had a good rapport with him) to establish whether the farmers would be willing to collaborate in the research. The *shugaba* gave his approval, so the choice of the site was confirmed (section 4.6.1 considers the process of establishing relations with farmers). Rayfield (Figure 3-1) was designated as a secondary research area and was visited on a few occasions so that farmers could be interviewed on SFM practices.

Delimi is located along the banks of the Delimi River, just north of Jos (Figure 3-1). The easiest way of accessing this area is to traverse the Permanent Site University Staff Quarters, which leads to the right bank of the river. The area can be reached further north by an access road from the University Hostels. Alternatively, the left bank can be reached through footpaths from the market of Farin Gada.

4.2.3 Preliminary interviews and meetings

Fieldwork began with preliminary semi-structured interviews (details on the interview technique can be found in section 4.7.2). This was for two reasons: firstly, information from the interviews was required to refine the details of the research and secondly, the interviews were a way of making contact with the farmers, raising their awareness about the research, and identifying potential collaborators. The interviewing centred on SFM and use of inorganic and organic fertilisers, particularly urban waste ash. Farmers were specifically questioned about the type of fertilisers they were intending to use, the type of soil that characterised their land, how it compared to various sites of their neighbour(s), the number of years a potential area had been cultivated, the type of crops they planned to grow and whether they were willing to collaborate in the research (see Appendix A). For logistical reasons the farmers selected for the interviews were simply those who were on their farms during the field visits. About 15 interviews were

[2] This is the Hausa word for 'head of the farmers'. All subsequent terms in italics will be Hausa words as in these locations this was the dominant ethnic group (as explained in 3.5).

conducted until all study farms were selected (4.2.5). The interviews continued even after sampling had begun so that comprehensive information on SFM strategies could be obtained.

4.2.4 The research approach: non-interference

As already mentioned in Chapter 1, one of the original goals of the thesis was to design field trials in collaboration with the farmers, to test the effectiveness of different fertiliser combinations. This was one way of discovering whether farmers were supplying adequate amounts of nutrients over the course of one season. The approach would have consisted of three or four trials to be run on the same farm according to the fertiliser recommendations of different individuals. The plan was actually discussed at great length with one farmer who was willing to allow a part of his land to be used for the trials. This strategy had the advantage that it reduced the problem of soil variability and would allow control of the inputs and the type of crops planted but had the disadvantage of being representative of only one farm. This would mean that, in any case, to look at the effects of cultivation in the long term, cultivated and uncultivated samples would still have to be collected from other farms. An alternative way of discovering whether soil fertility management strategies were effective or not, would base itself on soil testing on pairs of farms with similar soil but different fertiliser applications, using the SFM strategy typically adopted by the owner of each farm. This strategy would be more representative of the farming system (and would automatically permit the examination of the long term effects of cultivation on more than one farm), even if it would be subject to the uncertainty of soil type, the lack of control over crops planted and type of fertiliser applied.

After a preliminary assessment of the field conditions, this second approach of simply documenting and following the farming strategy chosen by different farmers, without interfering in their practices, was eventually selected and it was an important decision. Ideally, it would have been useful to combine both approaches but, apart from one individual, farmers could not be convinced to participate in a large-scale experiment (see 4.6.3). This was because farmers have little land and are reluctant to sacrifice a portion of it to new ideas or strategies. Each farmer is convinced of the efficacy of his own approach, having gained empirical knowledge about his land over years of practice and testing. Moreover, even if all farmers had agreed to a particular trial, this would not guarantee that they would all be in a position to carry it through (without guaranteed monetary solutions in the case of unexpected problems). Even the most co-operative farmers could not always behave according to plan because external factors would force them to make unexpected alterations. For this reason, certain data had to be estimated rather than measured directly (e.g. 4.2.8). Ultimately, the results yielded by the sampling and monitoring should be considered the outcome of case studies rather than rigorous trials. Nevertheless, the on-farm results are useful in portraying a general picture of the farming system and should be integrated with the results of the interviews and discussions with the farmers (see 4.7).

4.2.5 Farm selection

Choosing farms and collaborators was not a straightforward process. Even once it was decided that the non-interference approach should be adopted, it was not simple to find suitable locations. Two farms could share a similar soil type but have different combinations of crops or be out of synchrony in regards to time of planting. After preliminary interviews (4.2.3), the farms with the most similar management strategies (excluding SFM strategies of course) were selected. Additionally, soil cores from potential sites were also examined to define their textural and colour characteristics and find which adjacent farms had similar topsoil. Only the top 20-30cm were considered, as most vegetable crops have shallow rooting depth (Landon, 1984). The intention was to carry out an in-depth investigation with four farms on two soil types, but as a precaution against unexpected plan alterations, six farms on three soil types were selected for the thesis trials. These farms were chosen because: the plots had been under cultivation for at least 10 years; some of the farmers were planning to use town refuse ash, some were planning to use farm waste ash, some were not planning to use ash at all; they had different IF strategies; the particular plots selected were not subject to flooding during the rainy season and five of the six farmers were going to plant lettuce at least in the first half of the season; the farmers appeared positively disposed towards collaborating. It is clear that the choice of these farms cannot be compared to a rigorous farm trial but in the light of the circumstances and the decision of non-interference in the research (4.2.4), these farms are the best possible but not 'perfect' choice. The farms have been designated with the name of the owners[3] and the order given reflects the pairing (two farms on each soil type): Audu (Au) and Hassan (Ha); Salem (Sa) and Shitu (Sh); Abdullahi (Ab) and Musa (Mu). Soil type was classified according to the textural and colour characteristics of the topsoil and the opinion of the farmers. All six farms were sampled during the first half of the season after which the two pairs of farms with farmers who were collaborating well and providing good data were retained for further sampling whereas sampling from the other pair ceased (Ab and Mu). During the first half of the season Au, Ha, Sa, Sh, Ab were sown with lettuce as a main crop and additionally, Ha planted spinach on the ridges of the subplots. Mu planted carrots. During the second half of the season Au and Sh planted lettuce, Ha planted lettuce and beetroot, Sa planted carrots. It was difficult to establish precisely the number of years that each farm had been cultivated because of farmers' imprecise recollection. Furthermore, if the land had been farmed by different people, the current farmers would not necessarily know the total number of years it had been farmed. Approximately then, Au's land had been under cultivation for more than 11 years (Au had been farming it for four years, prior to that it had been farmed for 7 years by Ab, and before that it was being farmed by someone

[3] To preserve farmers' anonymity, names have been changed.

else); Ha's land for 40-50 years (by Ha's father); Sa's land for at least 13 years; Sh's farm for 10 years; Ab for 14 years or more; Mu for 12-15 years.

4.2.6 Soil sampling strategy

As already partly introduced in the previous sections, the soil sampling strategy was designed in order to:

1) Assess the average nutrient levels for each farm and identify possible deficiencies or toxicities (objective II);
2) Determine the changes in nutrient status of a farmed soil in respect to the uncultivated soil as a result of farming practices (long-term effects) (objective III);
3) Establish if a farmer's seasonal SFM strategy was meeting the crop requirements by checking that end-of-season nutrient levels returned to the beginning of season levels (short-term effects) (objective IV);
4) Discover if the practice of applying urban waste ash posed any risk in terms of heavy metal accumulation in the soil, and possibly in the food chain (objectiveV).

Objectives II, III and V could easily be resolved by collecting samples from cultivated and uncultivated sites. This was done for all six farms. The fulfilment of objective IV required a very specific soil sampling strategy, which could detect changes in variable levels over time while minimising the problem of spatial variability in soil. The sampling strategy described in the next paragraph is based on the reasonable assumption that by sampling very close to a fixed point, any differences in nutrient levels are likely to be caused by a temporal effect rather than a spatial effect. There will obviously be some unpredictable variability, because soil is a variable material and it is not exactly the same sample that is being measured over time, yet the samples are likely to be sufficiently similar to be considered the same 'individual', which is being tested at different times. This particular sampling design, known as a 'mixed two-factor within subjects analysis of variance design' (see 4.5.2) is more commonly used in the social sciences (Keppel, 1991), but it can be usefully applied to this situation, particularly because it requires fewer samples rather than when different samples are randomly selected at the various time points. The complete sampling cycle was carried out on four farms (Au, Ha, Sa and Sh) that were supported by good quality IF measurement data. Sampling stopped after the first major harvest period (see point 3 below) for Ab and Mu, who were retained for a few analyses only (see 4.4.2 for details).

Sampling was facilitated by a convenient 'grid' structure that is created by the farmers for irrigation purposes. The fields are divided into a network of small rectangular plots (which from now on will be referred to as 'subplots') and irrigation channels (see Figure 4-1). The subplots and channels are built by raising the soil into ridges. Water from the river is pumped into the channels and flows under gravity, submerging each subplot in turn. The details of the sampling strategy are as follows:

1) Ten subplots from each farm were selected and identified with a number, so that they could be sampled repeatedly at different time points.
2) The choice of the ten subplots was made by assigning a number to each subplot on the portion of land of interest, writing each number on a small piece of paper and drawing ten numbers from the whole batch.
3) Each subplot was sampled by collecting a core of topsoil with a soil auger from around the centre point. The centre was pinpointed each time by drawing two strings diagonally from the corners.
4) Ten samples for each time point were considered adequate because the plots in the study were very small, comprised between 0.02 and 0.1ha (see Table 6-10).
5) Ten control samples were also collected for each farm from around the boundaries of the study field (in December-January).

Sampling occurred at certain critical stages:

1) As soon as the subplots were created, at the beginning of the season, before any fertiliser was applied (T1);
2) One week after each round of fertilisation (but only during the first half of the farming season) (TF1, TF2, etc.);
3) After the first major harvest period (before the second major crop was planted) (T2);
4) After the final harvest period, at the end of the farming season (T3).

Stages 1 and 4 were essential to understand whether the crops' needs were being met over the course of the season, as if this was the case, soil nutrient levels were not expected to differ significantly between the start and end of the farming season. Stage 3 was also interesting (but not critical to the research) because it gave an indication of what was happening half way through the season. Moreover, farmers tended to apply ash (if they did at all) in the first half of the season, but rarely in the second half. Samples collected during stage 2 were used (along with samples collected during stages 1, 3 and 4) for a detailed inspection of the pH fluctuations during the farming season. This was done because one of the possible modes of action of ash is by raising the pH of the soil, and this was a way of testing whether any consistent pH changes can be observed after ash application (or indeed after IF application).

It has to be remarked that the collection of control samples was subject to a few uncertainties and difficulties. The Delimi area is intensively cultivated. Thus, it is very difficult to find uncultivated land that is adjacent to the farmed areas. Uncultivated sites could have been found further away from the river but sampling here was not advisable because of the risk of moving onto a different soil type. Controls could only be collected from the uncultivated borders of each study plot, and although samples were collected from grassy verges that appeared undisturbed (where in some cases fruit trees and/or permanent bushes were located), the possibility of cultivation practices having interfered with these portions of land at some point, cannot be entirely dismissed.

Figure 4-1: Irrigation channels

4.2.7 Study farm measurements

The question of whether farmers are meeting crop demand is resolved by combining data on soil nutrient levels with information on rates of fertiliser application. In order to calculate a rate of IF application it is necessary to know the area of each study plot. Measurements were made directly (as Phillips-Howard *et al.* (1990) had found that farmers frequently did not know the area of their land), using a 15m tape. Measurements were facilitated by the grid structure formed by the subplots. The irrigation channels were included in the area estimate because some IF is applied to the ridges, if crops (like spinach) are planted on them. Furthermore, successive irrigation cycles slowly wear down the ridges between subplots and channels so that they have to be re-built and it is likely that there is a degree of mixing of topsoil between the subplot, ridge and irrigation channel.

4.2.8 Inorganic fertiliser measurements

Each time a farmer applied IF the amount and the type/s used were recorded, as this information was required to understand whether farmers were supplying sufficient nutrients to satisfy crop demand, without depleting soil nutrient reserves. Whenever possible, IF was measured directly by weighing in a bucket with a spring balance. In other cases, the farmer's estimate had to suffice. This was because the farmer did not always fertilise on the arranged day. For example, a farmer would decide to fertilise on a Monday morning, but perhaps obtain the money to buy IF two days previously and fertilise then, for fear of not having any money left by Monday. Or, maybe, he would fertilise unexpectedly because he would decide that the crops were not growing adequately and needed a small amount of IF. For the most part, the farmers did not understand the importance of precise measurements, so if they needed to make changes in their working plan, they did so and just made note of what they had used in their own measurement units. This was particularly the case of the older farmers who were not as flexible and co-operative as the younger farmers, who instead gave advance warning in case of a change of plan, probably because of the friendly relations they had established with the field assistant. When the farmer made an estimate, it was sometimes approximate (half a 50kg bag of NPK or a third of a bag) or often expressed in the local unit, the *mudu*. The *mudu* is a volumetric measure, not a weight measure, and consists of a small bowl, which is filled in a similar way by all market sellers. An investigation by Harris (1995) showed that if sellers were asked to repeatedly measure out a *mudu* of a particular foodstuff, the weight results were quite consistent. Thus, during the research activities, IF salespeople were asked to measure out a *mudu* of each kind of IF so that the weight[4] could be recorded. This allowed conversion of the farmer's estimate from *mudus* to kilograms.

4.2.9 Ash measurements

All farmers in the study applied ash, with the exception of Sa, who did not think that the particular portion of land under study required it. Ab applied ash that he obtained by burning refuse which had been strewn across his low-lying land during the Delimi river floods of the previous rainy season. Au and Sh used ash produced by burning waste collected around the farm (leaves, branches, grass) whereas Ha and Mu applied town refuse ash.

The farmers did not seem to consider exact quantities of ash as important (whereas they had definite ideas about exact amounts of IF). With ash it was sufficient to throw enough to coat the leaves of the crops and give a fine covering to the soil (Figure 4-2). For this reason, the farmers did not always warn that they were going to apply ash, so an estimate had to suffice.

[4] A *mudu* of NPK15:15:15 weighed 1.9kg; a *mudu* of Golden NPK15:15:15 1.9kg; a *mudu* of Kampa (Compound NPK15:15:15) 2kg; a *mudu* of NPK27:13:13 1.7kg; a *mudu* of NPK17:5:5:17 1.8kg; a *mudu* of super-phosphate 2.25kg; a *mudu* of urea 1.6kg.

Exceptionally, a few farmers gave advance warning that they were going to apply ash and agreed for the ash to be weighed with a bucket and spring balance before application. In other cases, a direct measurement would have been possible but so much ash had to be applied that this would have interfered with the farmer's work speed. In this situation, the farmer provided a rough estimate of how many 'sacks' had been used over the portion of land in question and made arrangements for only one sack to be weighed out. Therefore, for the most part, ash measurements are approximate.

Figure 4-2: Farmer applying town refuse ash to lettuce crop

4.2.10 Testing for heavy metals

As discussed in 2.7, aim 3 of the thesis was to further the understanding of the risks posed by using urban waste ash in farming. There are clearly many potential dangers associated with this practice, but in this research only the assessment of risk of heavy metal accumulation in the soil and the food chain (objective V) was viable (because of lack of equipment and laboratory facilities in Jos for pathogen contamination or air pollution measurements, for example). Testing for heavy metal accumulation in the food chain is complicated and consisted of four stages:

1) The soil samples had to be tested in the laboratory for heavy metals to determine the plant-available levels. This would give some indication of the degree of contamination of the soil, even though it would not necessarily mean that crops were indeed taking up heavy metals.
2) The ash samples could be a source of heavy metals so they were analysed for total quantities to estimate the degree of contamination of the samples and the potential long-term contribution to the soil.

3) The river water had to be tested for heavy metals because it could not be excluded that the water was a source of contamination (particularly because the farms are downstream of Jos).

4) The crops had to be tested to establish conclusively whether heavy metals were being taken up and translocated to the edible portions of the plant.

4.2.10.1 Ash sampling

To estimate the average nutrient and heavy metal input of ash, small samples of the material were taken from the farmers. Ha and Mu contributed one small bag of ash each, whereas Sh provided three small bags of ash, as he applied the material on two separate occasions (so on one occasion two replicates were collected). Ab had a very large heap of ash (see 4.2.9), so it was possible to collect ten replicates from him to determine the material's variability. Unfortunately, Au applied ash unexpectedly, when no arrangements had been made to collect a sample.

4.2.10.2 Delimi River water sampling

The levels of heavy metals in irrigation water were determined on two samples collected in March 2002. Although one sample of the Delimi River water was collected a few days prior to the end of the fieldwork period in May 2001, and treated with nitric acid as soon as possible upon arrival in the UK, the analysis could not be carried out until April 2002 (when access to an ICP-Mass Spectrometer was finally possible). The sample was considered too old to be of any use, so it was excluded from the results analyses. In March 2002, University of Jos staff visited the University of Durham, and they were asked to bring two fresh water samples to Durham. At this time the rainy season had not started, water was at its lowest level, so heavy metals were likely to be very concentrated. These samples were also treated with nitric acid and frozen to minimise reaction of the heavy metals in the water during the brief storage period. Although these samples were not collected in the same season as the fieldwork, they can still provide an indication of potential nutrient and heavy metal input to the soil through irrigation.

4.2.10.3 Crop sampling

At the end of the farming season, ten samples were collected from each study farm that was going to be analysed for heavy metals (4.4.2). Au, Ha, Sh and Ab had planted lettuce whereas Sa had planted carrots. These crops were necessary to the study, so that the concentrations found in the plant tissues could be related to the concentration in the soil, and ultimately to the ash application. Yet, as it is known that some species are hyperaccumulators (Brooks, 1998; Raskin and Ensley, 2000), additional cabbage samples were collected from another part of Au's farm.

4.2.11 Soil, ash and crop pre-treatment

On the same day of collection, each soil sample was removed from the plastic packaging and spread onto sheets of clean white paper for air-drying. The samples were fragmented as much as possible while still wet because once they dried, they hardened to such an extent that it was almost impossible to break them down for sieving. Despite this precaution, grinding with a mortar and pestle was not sufficient for two soils (Au and Ha), for which a heavier instrument (a yam pounder) had to be used. After grinding, the soil was sieved through a 2mm mesh and replaced in the plastic bags.

Ash samples were also spread on sheets of clean white paper for air-drying and re-packaged once they were dry.

Crop samples were sun-dried and packed into large plastic bags. Lettuce and cabbage samples were not washed because of the potential for ash residue remaining on the crops and acting as a contaminant. Market sellers do not appear to wash these crops, although they may spray them with water during the day to keep them looking 'fresh'. Carrots instead were washed prior to drying because they obviously get contaminated with soil, and market sellers will wash them before marketing[5]. Before transport they were ground finely and finally packaged in paper envelopes for shipping to the UK. Cabbage required further treatment because it would not dry out completely. Despite lengthy spells in the open, each time it was returned to a closed environment, it re-gained some dampness. The cabbage could not be kept in the open indefinitely as the approaching rainy season brought strong winds and sudden rainstorms. Eventually the cabbage had to be oven-dried at low temperature in a domestic oven.

4.3 PROVIDING AN APPRECIATION OF THE ROLE PLAYED BY URBAN WASTE ASH BY EXAMINING ITS CHEMICAL CHARACTERISTICS

This section describes the process of data collection used to address objective VI (although these data were also merged with data collected in the study area—see 4.2.10.1), which in turn contributes to the partial appreciation of aim 3. As already discussed in 4.1, aim 3 is strongly linked to aim 1, as information collected to address this aim contributes to the full understanding of aim 3.

4.3.1 Approach

Understanding the general role ash plays in the farming system and its possible effects on the soil required a combination of techniques. Firstly, many different types of ash samples

[5] Women traders, who purchased small quantities of produce directly from the farmers, were frequently observed washing carrots and other root crops in the Delimi river, before head-loading the produce to the nearest market.

were analysed for their nutrient and heavy metal status and their pH. Secondly, farmers were interviewed on their perception of the modes of action and utility of ash (4.7.2.1). These results could then be combined together for the formation of theories on its possible mode/s of action, which could also be matched to research, reported in the literature, carried out on similar materials like coal-fly ash. The isolation of the proper effects of ash would, of course, require rigorous laboratory and 'in the field' experiments. At this stage, these were not logistically possible, thus, the study cannot provide definite answers but can certainly advance possible explanations, to be tested more thoroughly in the future.

4.3.2 Sampling from around the town and in the field

Farmers use ash derived either by burning domestic refuse, farm wastes or town refuse. 'Farm' ash is produced by burning grass, leaves and branches collected from around the farm, and usually takes about two to three days to prepare. 'Town refuse' ash derives from the urban waste that is typically found in heaps along the sides of roads. These heaps are particularly large in the vicinity of markets and there is little or no removal on the part of the council. For this reason, the heaps are periodically set on fire and ash is produced, and this reduces the volume of the waste. Farmers in Delimi can obtain waste in two ways. They can ask the council (JMDB) to transport a load of refuse to the farm (with one of the few operative trucks remaining) and then the waste is treated in the farming area itself, by burning, if it still requires it, and then sorting to remove materials that did not burn. The waste can take up to a week to finish burning. Alternatively, farmers can hire pick-up trucks to go directly to the waste heaps and this can be an advantage because the farmers can mostly select the ash component.

To gain information on the range of crop nutrient and heavy metal levels, ash samples had to be collected from various locations. Five samples were collected from farmers in the study area (two of these consisted of ten replicates each to test for variability) and other samples were collected from nine sites in town[6], giving a total of 59. Replicates could be collected only from larger sources.

4.4 LABORATORY ANALYSIS

All samples collected during fieldwork (4.2 and 4.3) were transported back to the U.K. for laboratory analysis. The next sub-sections will provide details on the choice of variables measured and the type of method used, whilst section 4.5 deals with the statistical analysis of the results. These sections describe activities that occurred in Durham. Sections 4.6 and 4.7 continue reporting on the remaining fieldwork activities in Jos.

[6] The refuse heaps were located in the University of Jos Senior Staff Quarters on Bauchi Road; in front of the University of Jos gates on Bauchi Road; in Dogon Dutse Road; in Farin Gada market area; in Katako market; in Gada Biyu, Yan Shanu and Delimi districts; in the Anglo-Jos industrial area.

4.4.1 Transport to the UK

All soil and ash samples were split before being transported back to the U.K. to leave back-up samples in Jos. Every soil sample transported back to the UK was approximately 100g, whereas the ash samples were smaller. Samples were packaged tightly in strong plastic bags and transported in an metal trunk.

The water samples from the Delimi River were conserved in small plastic bottles and sealed tightly.

All plant samples were packaged in envelopes and then in plastic bags. They were not split because of the possible need of a large amount of sample for the tests.

4.4.2 Soil sample analysis

The variables considered useful for the case study are the following: organic carbon; total nitrogen; pH; exchangeable bases (calcium, potassium, magnesium and sodium); cation exchange capacity (CEC); available phosphate; available heavy metals (iron, manganese, zinc, copper, nickel, cadmium and lead). Organic carbon was chosen because it is taken as a measure of the quantity of organic matter in the soil, which in turn provides a crude measure of the fertility status of the soil (Landon, 1984). Nitrogen occurs in soils in several different forms, organic compounds, nitrate and nitrite anions and ammonium ions. Nitrates are the main forms of N used by plants (Landon, 1984). NO_3-N is considered a good measure of available nitrogen, especially in hot, dry environments, where the crops are irrigated and high-yielding and soil organic matter content is low. Unfortunately, it is complicated to measure as the sample must be treated quickly to stop mineralisation, otherwise it would no longer be representative of the field status (Dahnke and Johnson, 1990). In this research project the samples were stored for a long period of time before analysis, so it was preferable to use a measurement that would be relatively unaffected by storage conditions. Thus, total nitrogen by the Kjeldahl method was chosen as a N measurement as it is used in routine soil analysis (Landon, 1984). The determination of pH is also routinely performed on soils even though it is argued that the values do not have a precise significance because field values can be strongly affected by localised redox states, the concentrations of soluble salts in the soil solution, the concentration of CO_2 in the air, the depth of sampling and the season (Landon, 1984). Nevertheless, pH is a useful measurement, because it strongly affects the availability of elements in the soil, so it can suggest a potential for toxicity or deficiency of the various elements (Landon, 1984). The exchangeable bases and CEC provide information on the soil fertility status (Landon, 1984; FAO, 1990). The phosphorus measurement should ideally be a method that measures both the immediately available P and the potentially available (or fixed) P but this is not done because it is too complicated for routine analysis. Instead, there are several standard methods for testing available phosphorus. Their applicability depends very much on the soil pH (Landon, 1984). In this research the determination of available phosphate, extracted with acetic acid, was carried out.

Seven heavy metals were chosen for the research project for different reasons. Cadmium, nickel and lead can pose a health risk to humans via direct ingestion of the soil (this is especially the case for Pb), or through plant uptake, and food chain contamination (Risser and Baker, 1990). Iron, manganese, copper and zinc are of interest because they are essential plant micronutrients (Landon, 1984). A very accurate analysis would require the use of more than one extractant, but time and resource constraints in the research limited the number of extractions that could be performed to one.

There are advantages and disadvantages with all extractants (particularly as, currently, no single one has been developed that is suitable for all heavy metals required in this research). Mild extractant methods such as $CaCl_2$, $Ca(NO_3)_2$, $NaNO_3$ and NH_4NO_3 are generally better indicators of immediately available metals but their application to predicting plant availability has yielded mixed results (McLaughlin *et al.*, 2000). Organic extractants such as EDTA and DTPA act by desorbing metal ions from exchange sites on the solid phase into solution and are better indicators of potential toxicity than immediate toxicity (McLaughlin *et al.*, 2000). Both extractants are widely used (e.g. EDTA has been adopted as a routine soil test by MAFF—MAFF, 1986; DTPA is used in many experiments reported in the literature) but have different limitations. EDTA has a tendency to extract metals from non plant-available pools of metals, and so overestimates phytoavailability (Sterckeman *et al.*, 1996; McLaughlin *et al.*, 2000). For this reason DTPA was preferred to it. There are controversies surrounding the use of DTPA (Quevauviller *et al.*, 1996), but Connor (1988) reviewed the use of the test and warned that the successes or failures recorded in the literature in predicting plant metal concentrations could be ascribed simply to the correct use or misuse of the test. He emphasised that the test had been developed to identify near-neutral and calcareous soils with insufficient available Zn, Fe, Mn and Cu and any other application would be subject to difficulties. Norvell (1984), who co-developed the DTPA soil test with Lindsay (Lindsay and Norvell, 1978), has suggested that to improve the performance of the DTPA test in acid or metal-polluted soils the concentration of the chelating agent, the number of extractions or the extractant:soil ratio could be changed. Therefore, in this research project, although it is acknowledged that there is still need to develop an effective and standardised procedure to determine deficiency and toxicity levels of heavy metals in the soil (in agreement with McLaughlin *et al.*, 2000), DTPA was considered an acceptable extractant. It provides an indication of 'potentially' bioavailable metals and it was designed to predict deficiencies for Fe, Mn, Zn and Cu in near neutral soils (and the farms had near neutral soils, except for Sa and Mu) (Connor, 1988), and it also seems suitable for correlating to plant Cd concentrations (Quevauviller *et al.*, 1996). In this research Ni and Pb were also extracted with the other metals, but these results only provide a general indication of soil levels, as DTPA is not considered to be a good extractant for either Ni (Quevauviller *et al.*, 1996) or Pb (Connor, 1988).

Table 4-1 clearly illustrates which batches (T1, T2, T3 or C) were tested for a particular variable in Au, Ha, Sa and Sh's farms.

Table 4-1: Time points tested for a particular variable for the study farms

Variable tested	Au	Ha	Sa	Sh
Org C	T1, T2, T3, C	T1, T2, T3, C	T1, T2, T3, C	T1, T2, T3, C
Total N	T1, T2, T3, C	T1, T2, T3, C	T1, T2, T3, C	T1, T2, T3, C
pH	T1, T2, T3, C	T1, T2, T3, C	T1, T2, T3, C	T1, T2, T3, C
Ex. Na	T1, T3, C	T1, T3, C	T1, T3, C	T1, T3, C
Ex.K	T1, T3, C	T1, T3, C	T1, T3, C	T1, T3, C
Ex.Ca	T1, T3, C	T1, T3, C	T1, T3, C	T1, T3, C
Ex.Mg	T1, T3, C	T1, T3, C	T1, T3, C	T1, T3, C
CEC	T1, T3, C	T1, T3, C	T1, T3, C	T1, T3, C
Avail. P	T1, T2, T3, C	T1, T2, T3, C	T1, T2, T3, C	T1, T2, T3, C
Avail. Fe	T3, C	T3, C	T3, C	T3, C
Avail. Mn	T3, C	T3, C	T3, C	T3, C
Avail. Zn	T3, C	T3, C	T3, C	T3, C
Avail. Cu	T3, C	T3, C	T3, C	T3, C
Avail. Ni	T3, C	T3, C	T3, C	T3, C
Avail. Cd	T3, C	T3, C	T3, C	T3, C
Avail. Pb	T3, C	T3, C	T3, C	T3, C

T1, T2 and T3= beginning, middle and end of the farming season, respectively. C= control

In addition to these analyses, Ab and Mu's samples were tested for a few variables even though sampling ceased after T2, because they represented a different soil type, so it was useful to compare a few major properties to those of the other four farms. Therefore, Ab and Mu's T2 and C batches were tested for organic C, total N and pH. Furthermore, as Ab had a history of using a lot of town refuse ash, his T2 and C batches were also tested for all seven heavy metals. It must be added that, although it is not obvious from Table 4-1, pH was actually measured on every single soil sample available (for all farmers and for all time points described in 4.2.6). This was the only variable that was tested in such a detailed way, to examine the seasonal pH fluctuations and determine whether any particular fertilisation practices (such as the application of ash, which Phillips-Howard and Kidd (1991) thought acted by raising the pH of the farms) could be linked to any pH changes.

4.4.2.1 Duplication of analyses

Ideally, best laboratory practice would require each sample to be run in duplicate to check for analytical precision. Unfortunately, time was a strong limiting factor and the duplication of every sample would have severely reduced the total number of samples for the research. For this reason, fewer samples were duplicated but this was combined with an alternative strategy to check for consistency (this is explained in Appendix B).

4.4.2.2 References for methods

The following sections will describe the analytical methods chosen for each variable. Only a brief outline will be presented, as most methods referred to are described in MAFF (1986) or Hesse (1971). Methods in 4.4.2.5, 4.4.2.6, 4.4.2.7, 4.4.2.8, 4.4.2.9, 4.4.2.10, 4.4.2.11, 4.4.3.1, 4.4.3.2 refer to standard procedures described in an internal publication of the Geography Department, University of Durham (Alexander, 2000). This last author in particular, comprehensively discusses and compares various methods that have been developed. The method in 4.4.2.3 was taken from another internal publication of the Department of Geography, University of Durham (Davies, F.), whilst 4.4.3.3 and 4.4.4 refer to EPA Method 3051 (CEM, 2000).

4.4.2.3 Particle size

Particle size was determined using a Beckman Coulter LS 230 Granulometer. The samples were prepared according to a Department of Geography, University of Durham method (Davies, F.), by addition of sodium hexametaphosphate, before analysis on the granulometer. Each soil sample was classified according to the USDA textural system (USDA, 1972).

4.4.2.4 Soil colour

Soil colour was judged according to the Munsell notation. As samples could not be tested in the field, the air-dry sample was moistened and matched to the nearest colour on the Munsell colour chart.

4.4.2.5 Organic carbon

Organic carbon was determined by a process of wet oxidation with a technique that is based on the Walkley-Black method (Alexander, 2000; Hesse, 1971).

4.4.2.6 Total nitrogen

Total nitrogen was measured with a modified version of the Kjeldahl technique (Alexander, 2000; Hesse, 1971; MAFF, 1986). A micro-Kjeldahl digestion rack was employed to reduce the time required for the digestion.

4.4.2.7 pH

The pH was measured in the field with a Jenway Portable pH meter on every available sample except for two batches of samples, which were collected a few days prior to the end of the fieldwork period. These two batches were analysed in the laboratory with a Jenway glass electrode pH meter and certain batches were also repeated in the laboratory to check that field and laboratory equipment were yielding similar results. Both field and laboratory tests were based on the saturated paste method (Alexander, 2000). Results were consistent, so the field data were judged adequate.

4.4.2.8 Conductivity

The purpose of measuring conductivity was simply to decide whether the soils required pre-treatment, before the determination of exchangeable bases and CEC. For this reason it was necessary to test only a few of the samples. The same paste used for the pH readings (section 4.4.2.7) in the laboratory was used in the determination of conductivity with an EEL Conductivity Bridge. The results for conductivity were all below 0.5dS/m.

4.4.2.9 Exchangeable bases and CEC

Exchangeable bases and CEC were determined by sequential leaching with an excess amount of 1M ammonium acetate (buffered to pH 7) and 1M sodium chloride of the same sample. As the measurements for conductivity showed that the soils had a conductivity of less than 0.5dS/m, no pre-treatment of the soil was necessary (Alexander, 2000). The exchangeable bases were then determined on the Varian SpectrAA 220FS Atomic Absorption Spectrophotometer (see Appendix B for wavelengths and standards for each element). The CEC was determined by titration following distillation on a Markham apparatus.

4.4.2.10 Available phosphorus for soils with a pH<7

Hesse (1971) discusses at length the problems of choosing a suitable available phosphorus extractant for any one soil. Although MAFF (1986) now recommends Olsen's method for all soils, this choice has been questioned for acidic soils. As the soils in the study area were generally in the range of pH 6 to pH 7, 0.5M acetic acid was used as an extractant (Alexander, 2000). Phosphorus was determined on a Cecil Instruments CE 272 Linear Readout Ultraviolet Spectrophotometer, with the wavelength set at 640nm, using a blank solution (the blank being the acetic acid) and three phosphorus standards (1, 2, 5ppm).

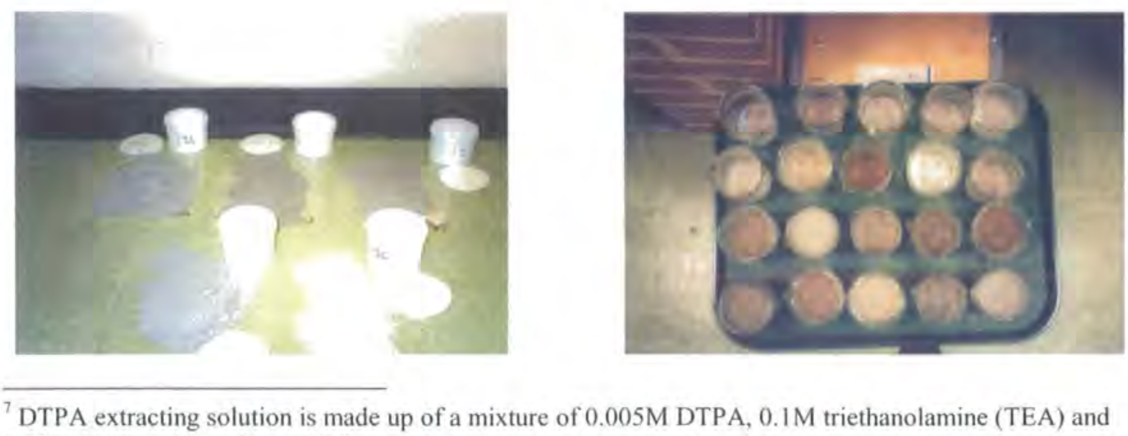
4.4.2.11 Available iron, manganese, zinc, copper, nickel, cadmium and lead

The literature lists several methods for the extraction of available heavy metals from soil (Rowell, 1994; MAFF, 1986; Hesse, 1971). The different critical levels will depend on the extracting reagent used and the crops grown, so the predictability of any particular soil test will depend on how well the soil test results are correlated with greenhouse or field crop response data (Prasad and Power, 1997). In fact, the most common soil testing methods do not relate well to field calibration studies (Landon, 1984). At present, most guidelines for maximum permissible levels of heavy metals in soil are based on 'total' amounts determined after a strong acid digestion (e.g. See Annex II C in Council Directive 86/278/EEC). Various studies though, have shown that total metal concentrations do not illustrate the complexity of relationships within soil systems. For example, Stephens *et al.* (2001) discovered that in samples of dredged canal sediment the heavy metals were differently available (up to 40% of the 'total' metals could be in plant-available form) and generally Zn and Cd were the elements more readily extracted with DTPA. Singh *et al.* (1998) reached similar conclusions as they found that the ratio of DTPA-extractable metals to total contents decreased in the order: Cd (38%)>Cu (28%)>Zn (26%)>Pb (13%)>Ni (10%). Indeed, significant proportions of total metals may be present in the plant-available form, and it is advocated by some that regulations and guidelines should take into consideration both the immediately and potentially bioavailable forms rather than the total concentrations of metals in the soil (McLaughlin *et al.*, 2000). The controversies surrounding the use of different extractants have already been summarised in 4.4.2, along with the reasons for choosing to use diethylene-triamine-pentaacetic acid (DTPA) solution[7] (Alexander, 2000). After extraction with DTPA, the samples were analysed on the Varian SpectrAA 220FS Atomic Absorption Spectrophotometer for Fe, Mn, Zn, Cu, Ni, Cd and Pb (see Appendix B).

4.4.3 Ash sample analysis

The ash samples were tested for exactly the same variables as the soil samples but in some cases different techniques had to be applied. Almost every ash sample was tested for all variables, but in some cases some tests were omitted in favour of others because the amount of ash available was very low. The exact number of samples tested for each variable is summarised in Table 4-2. For simplicity the ash was grouped into three batches: one consisted of samples collected from different neighbourhoods in Jos and from the study area (4.3.2); another (Ab town refuse ash) was a batch of ten 'replicates' from a truckload of town refuse ash (4.3.2); the third batch of 'replicates' (Ab river ash) was derived from rubbish that had been strewn across the floodplain by the Delimi river during the rainy season (4.2.9). Figure 4-3 provides an example of the colour variability of different ash samples.

Figure 4-3: Ash samples



[7] DTPA extracting solution is made up of a mixture of 0.005M DTPA, 0.1M triethanolamine (TEA) and 0.01M $CaCl_2$, adjusted to pH 7.3.

Table 4-2: List of variables tested for groups of ash samples

Variable tested	*Samples from Jos and from the study area*		*Ab town refuse ash*		*Ab river ash*	
	Tested	N°samples	Tested	N°samples	Tested	N°samples
Organic C	✓	39	✓	-	-	10
Total N	✓	39	✓	10	✓	10
pH	✓	15	-	-	-	-
Total Na	✓	39	✓	10	✓	10
Total K	✓	39	✓	10	✓	10
Total Ca	✓	16	✓	10	✓	10
Total Mg	✓	39	✓	10	✓	10
Available P	✓	39	✓	10	✓	10
Total Fe	✓	39	✓	10	✓	10
Total Mn	✓	39	✓	10	✓	10
Total Zn	✓	39	✓	10	✓	10
Total Cu	✓	39	✓	10	✓	10
Total Ni	✓	39	✓	10	✓	10
Total Cd	✓	39	✓	10	✓	10
Total Pb	✓	39	✓	10	✓	10

✓ = Indicates whether a certain variable was tested on a particular batch of ash. 'N° samples' shows how many samples in that batch were actually tested.

4.4.3.1 Organic carbon, total nitrogen and pH

The methods employed to measure organic carbon, total nitrogen and pH in the ash samples are the same techniques used for the soil in sections 4.4.2.5, 4.4.2.6 and 4.4.2.7.

4.4.3.2 Available phosphorus

Hesse (1971) pointed out that in calcareous soils an acidic extractant was not suitable. Various methods based on alkaline solutions have been developed for soils with a pH>7. Although the material in question is ash and not soil, as there is no recommended procedure for ash, the samples (which had pH>10) were tested according to Olsen's method. Phosphorus was determined on a Cecil Instruments CE 272 Linear Readout Ultraviolet Spectrophotometer, with the wavelength set at 660nm, using a blank solution (the blank being the acetic acid) and three phosphorus standards (1, 2, 5ppm).

4.4.3.3 Total (nitric acid extractable) heavy metals and base cations

Ash was tested for total (nitric acid extractable) heavy metals and total base cations. The determination of total Na, K, Ca, Mg, Fe, Mn, Zn, Cu, Ni, Cd and Pb was carried out with microwave-assisted digestion (CEM's MARSX Microwave system) according to the Environmental Protection Agency's (EPA) Method 3051 (CEM, 2000). The determination of total metals was preferred to available metals because the latter method indicates only the immediate contribution to the soil, whereas the former can also give an indication of the potential for releasing the elements to the soil over time. Ideally, both total and available elements would have been measured but logistical constraints only allowed for one test. The samples prepared with microwave-assisted digestion were then analysed on Varian's SpectrAA 220FS Atomic Absorption Spectrophotometer (see Appendix B).

4.4.4 Crop sample analysis

Six crop batches (four lettuce batches from Au, Ha, Sh and Ab's farms, one carrot batch from Sa's farm and one cabbage batch that originated from Au's farm, but not from the portion of land under study) were analysed for total (nitric acid extractable) Fe, Mn, Zn, Cu, Ni, Cd and Pb. Each batch consisted of ten replicates, except in the case of cabbage and carrot, where one sample from each was lost during preparation (samples were vented from the microwave vessels because of excessive build up of pressure within the vessel cavities). Samples were first digested with hydrogen peroxide to break down organic matter and then analysed with the same technique used for the ash (4.4.3.3). However, as the dilution factor brought levels of certain elements below detection limits of the Varian SpectrAA 220FS Atomic Absorption Spectrophotometer, the metals were determined on a PerkinElmer Elan 6100 DRC Plus ICP-Mass Spectrometer. Further details of the procedure can be found in Appendix B.

4.4.5 Water sample analysis

The two water samples collected from the Delimi River were simply filtered and tested to determine the concentration of Na, K, Ca, Mg, Fe, Mn, Zn, Cu, Ni, Cd and Pb. This was a semi-quantitative analysis carried out by calibrating the PerkinElmer Elan 6100 DRC Plus ICP-Mass Spectrometer with a single solution. See Appendix B.

4.5 STATISTICAL ANALYSIS

Almost all mathematical and statistical procedures were carried out using Minitab software. The exceptions were the multiple comparison tests carried out following the 'mixed two-factor within subjects analysis of variance design', according to Keppel's (1991) procedure, which were performed using a Microsoft Excel spreadsheet.

4.5.1 Transformation of soil variable data

It is important to observe the shape of a distribution of a data set to decide the kind of statistical analyses that can be applied. The use of parametric statistical tests presupposes that the underlying population/s from which the samples derive are normally distributed. Parametric tests are usually preferred to their non-parametric equivalents because they are more powerful and retain information about the mean (Sheskin, 1997). No study has been carried out for the soils on the Jos Plateau to look at the distribution of the variables of interest (Alexander, Pers. Comm.). So, the shape of the distributions was examined by plotting the data for every element as a histogram, and for those distributions that were non-normal (or skewed), the data were transformed appropriately so as to obtain more normal distributions. Table 4-3 lists the transformations used.

Table 4-3: Transformations applied to variable data sets

Variable	*Original units*	*Transformation*	*Formula*
Organic carbon	g $100g^{-1}$	-	-
Total nitrogen	g $100g^{-1}$	Logarithm to base 10	Log10(100* g $100g^{-1}$)
Exchangeable sodium	$cmol_{(c)}$ kg^{-1}	Reciprocal	Log10(100*$cmol_{(c)}$ kg^{-1})
Exchangeable potassium	$cmol_{(c)}$ kg^{-1}	Reciprocal	Log10(100*$cmol_{(c)}$ kg^{-1})
Exchangeable calcium	$cmol_{(c)}$ kg^{-1}	Square root	Sqrt(100*$cmol_{(c)}$ kg^{-1})
Exchangeable magnesium	$cmol_{(c)}$ kg^{-1}	Logarithm to base 10	Log10(100*$cmol_{(c)}$ kg^{-1})
CEC	$cmol_{(c)}$ kg^{-1}	-	-
Available phosphorus	mg $100g^{-1}$	Square root	Sqrt(mg $100g^{-1}$)
Total iron	mg kg^{-1}	Logarithm to base 10	Log10(mg kg^{-1})
Total manganese	mg kg^{-1}	-	-
Total zinc	mg kg^{-1}	Square root	Sqrt(mg kg^{-1})
Total copper	mg kg^{-1}	Logarithm to base 10	Log10(100* mg kg^{-1})
Total nickel	mg kg^{-1}	Logarithm to base 10	Log10(100* mg kg^{-1})
Total cadmium	mg kg^{-1}	Logarithm to base 10	Log10(100* mg kg^{-1})
Total lead	mg kg^{-1}	Logarithm to base 10	Log10(100* mg kg^{-1})

- = original data distribution was approximately normal so no transformation was required.

4.5.2 Choice of statistical techniques for analysing soil sample data

The data collection strategy adopted in the field (4.2.6) determined which statistical techniques could be used on the data. These will be discussed in the next paragraphs.

In the first instance, it must be remembered that one of the purposes of the sampling strategy was to distinguish between farms in terms of nutrient parameters and assess whether these differences were the result of intrinsic soil characteristics and/or long-term cultivation effects (objective III). To do this, a 'two-way analysis of variance' (two-way anova) was applied to the control and cultivated soils for every farm (Dytham, 1999; Yates, 1937). In this context, the test can distinguish between farms averaging across cultivated and control samples (effectively isolating farms on the basis of soil type—this is a 'Farm effect'), and pinpoint the effects of cultivation by identifying differences between cultivated and control averaging across farms ('Status' effect). A significant result was followed up with Tukey's Honestly Significant Difference (HSD) test. The two-way anova also looks for a 'Farm*Status' interaction effect: if this is significant it implies that differences between farms are not the same at the two levels of control and cultivated soils and/or differences between controls and cultivated are not significant across all farms (or do not go in the same direction). In the event of a significant interaction effect the alternative strategy of conducting analysis of variance evaluating all levels of one factor across only one level of the other factor was employed (Sheskin, 1997; p.503). Then, any one-way anova that resulted significant was followed up with Tukey's HSD test. There was an issue concerning which cultivated samples should be compared to the control samples. Control samples were collected once, either in December or January, and this is more or less equivalent to the middle time point for the cultivated soils. So, it could be argued that the control set should be compared to the middle time point set (T2). This, though, would not always be possible because time and resources had limited the number of samples that could be analysed to one time point batch for the heavy metals (the end of season samples, T3), and two batches for the CEC and exchangeable bases (T1 and T3). An alternative approach could have consisted in pooling all available data but then different variables would be represented by 10, 20 or 30 replicates. The final decision led to the inclusion of T2 cultivated samples if they were available (organic carbon, total nitrogen, pH, available phosphorus) or T3 cultivated samples if T2 were not available (remaining variables).

In the second instance, it will be recalled that another purpose of the sampling strategy (objective IV) was to gauge the changes in nutrient levels over the whole farming season (short-term effects). This was addressed with a specific soil sampling strategy (described in detail in section 4.2.6) that is based on a statistical design known as a 'mixed two-factor within subjects analysis of variance design' (Sheskin, 1997; Keppel, 1991). In this situation, the model was used to detect whether there were any changes in a variable level over time ('Time' effect), what the overall differences between farms ('Farm' effect) were in terms of nutrient levels, and also highlight if there were any interaction effects between time and farms. Significant results were followed up with multiple comparison tests illustrated by Keppel (1991). This test also identifies differences between farms but the results would not necessarily match the results obtained with the 'two-way anova'. The latter test uses a single time point (either T2 or T3) but pools cultivated and control soils for the same farm. The 'mixed two-factor within subjects anova' instead looks for differences purely in terms of the cultivated soils and obviously pools all the available time points.

Ideally, these two approaches could have been combined into a complex three-way factorial analysis of variance model comprising a 'Farm' effect, a 'Status' effect and a 'Time' effect. This, though, would have required a balanced sampling procedure so that controls would have been sampled at the same time points of the cultivated soils (instead of once) and always from very close to the original location. Furthermore, all samples from all time points and farms would have had to be tested for all variables to maintain the balanced design. It is clear that this would not have been practical. From a fieldwork standpoint it would have been complicated as locating the original positions of each control sample, without reference points, would have been difficult and imprecise. From a laboratory work perspective, the drastic increase in the number of control samples would have necessarily required the reduction of variables tested or the number of farms studied. As one of the goals of the thesis was to obtain a perspective on the effectiveness of different SFM strategies, reducing the number of farms, and the variables tested, to increase control samples, would diminish the value of the work and lead to ineffective use of resources.

In the third instance, it will be recollected that one particular variable was studied in-depth and separately from the other variables because it was tested on every single sampling set collected during the research project (see 4.2.6): this was the pH. The pH testing was done during fieldwork with a portable pH meter on every time point (before fertiliser application—T1, after every fertiliser application–TF1 to TF_X, after the first major harvest–T2, and at the end of the farming season–T3). The analysis on the whole sampling set allows the examination of pH throughout the whole season, including after application of IF and ash. The 'mixed two-factor within subjects analysis of variance model' could not be used because the farms had a variable number of sampling sets (as some farmers might apply fertiliser in two rounds, others in three or more), so the farms were individually tested using a 'single-factor within subjects design' (Keppel, 1991). The limitations of the statistical test mean that each farm had to be considered separately, and it was not possible to search for overall differences between farms (averaging across all time points), nor to identify common time trends averaging across farms. This is not too problematic because, in fact, the pH was analysed in a second way also (like the other variables), by using only T1, T2 and T3 with farms Au, Ha, Sa and Sh to examine changes over the whole season and differences between farms.

4.5.3 Analysis of ash sample data

The ash sample data were analysed using descriptive statistics, which was sufficient, as the purpose of collecting ash samples was to gain a general impression of the range of nutrient variables and determine whether or not ash could be considered a homogeneous material. To facilitate analysis, the samples collected (4.3.2) were divided into three groups. The first group consisted of samples taken from different locations around Jos and from the farms, and provided an indication of nutrient variability across different sites. The second and third group both belonged to Ab and consisted of ten replicates each, one batch came from a truckload of JMDB town refuse and the other from river-borne refuse). These were analysed to give an indication of internal variability within the heaps.

4.5.4 Analysis of crop sample data

Each crop batch was analysed in the first instance with descriptive statistics for every variable to form an impression of average values and variability. Following this, one sample (from Au's lettuce batch) was discarded because it was clearly an outlier. It had probably been contaminated by soil particles. A few other samples (mainly in Ha's batch) raised suspicions because they appeared very high but they were not as obvious as Au's sample, so they were retained in the subsequent analyses. One-way analysis of variance was then employed to compare different batches and determine whether any batches had significantly lower or higher values for a particular variable. In addition, mean DTPA-extractable soil levels were plotted against mean crop concentration for each farm (for every variable) to contribute to the understanding of possible controlling factors for the uptake of heavy metals by crops. This exercise clearly had no statistical value because it was not carried out as a formal regression analysis (as there were not enough data points for this).

4.5.5 Analysis of water sample data

Water sample data were not analysed because the determination on the ICP-Mass Spectrometer was semi-quantitative.

4.6 MAKING CONTACT WITH FARMERS

Before discussing the techniques used in order to investigate the socio-economic circumstances (4.7) in which the research took place, I think it is important to address the problems related to making a connection with the people who are the focus of research (Figure 4-4). This section is therefore an acknowledgement of the fact that fieldwork is subject to many vagaries, the reaction of the people being researched being a very important one.

Figure 4-4: Farmers from the Delimi study location (left hand photo) and interviewing a farmer (right hand photo)

4.6.1 Establishing relations with the farmers

The most crucial phase of the research process consisted in gaining the consent and co-operation of the people in the study area where the research was based. I had come to Nigeria under the auspices of a British Council link that connected my department at Durham with the 'Department of Geography and Planning' at the University of Jos. In this I was fortunate, because I could benefit from the experience, contacts and willingness to collaborate of local researchers. I passed the first period of my stay in Jos visiting different field sites and discussing the relative merits of each site with lecturers of the University. For reasons already mentioned in 4.2.2 I decided to base my field trials at the Delimi production site. I decided that the other key production areas could be included in the survey, (4.7.1) and visited briefly to gather information to make comparisons across areas. The first meeting was successful as the *shugaba* approved the research, provided some background information and even volunteered his land for the trials. At this point, the dry season had not commenced in full, so a short delay intervened before I could begin fieldwork in earnest.

Forging relationships with the farmers was not straightforward and, indeed, I realised that every connection evolved in different ways over the course of the months. Many initial impressions were subsequently over-turned, and I realised that personal bonds counted far more than anything else in the success of the research, but I could not necessarily control these personal relationships. Many writers have documented the realities of coming face-to-face with different cultures (e.g. Twyman *et al.*, 1999), and before embarking on fieldwork I had reflected on how my positionality would influence the outcome of my research. I considered how the farmers' perception of me would influence the type of information I could access. I reflected on the fact that I was young (in a culture where young equals inexperience, or, perhaps, ignorance), a female (where male is dominant over female), doing a 'male' task, white (where white equals rich and powerful), and a non-Muslim (in a predominantly Muslim DSIVP farming community). In retrospect I wonder whether this exercise was useful or not: is there not the danger of over-reflecting on positionality? I am of the opinion that although it is good to acknowledge that who you are will influence the kind of information you can get access to, there is the risk that you enter the field with too many misconceptions about how people are going to perceive you. And this can actually lead you to behave inappropriately when, in fact, you are trying to avoid behaving inappropriately! On one occasion I attended a meeting to introduce my research to the farmers. I was worried about appearing 'superior' or the Western 'problem-solver', so I chose to sit on the ground, as the other farmers did. When the *shugaba* finished introducing us, my interpreter, on the other hand, stood up to translate my speech, and after the meeting we had a discussion about this. He explained that in the Hausa culture, if an elder person is sitting on the ground, it is a mark of respect that the younger person should stand in front of them (unless he is given permission to sit). So, in fact, I would have shown more respect if I had stood up during the speech. A further problem I have with all the reflections on positionality is, what happens when you spend a lot of thinking time on how your respondents are going to perceive you and, in fact, they do not seem to perceive you at all, but they only relate to your interpreter (see 4.6.2)? Is his positionality more important than yours, after all? How do you react to that? I found that I passed many months feeling slightly invisible, and if farmers did consider me, it had little to do with my gender and religion. The biggest problems were my age (which worked for and against me) and my supposed status. The hardest misconception to overcome was that I was rich and powerful and could bring benefits to the community. Although the approval of the *shugaba* was crucial and necessary, and certainly could not be by-passed, it still did not guarantee the other farmers' goodwill. In fact, after a couple of days of the preliminary interviews (4.2.3), a few farmers queried what benefits they would be receiving by collaborating, and this prompted the *shugaba* to call a general meeting.

The following week the elder farmers convened for a meeting so that the purpose of the research could be presented to them. After it had been established that I was a student and I could not bring them direct benefits, the group approved the research, granted access to their land and agreed to be interviewed. This acceptance though, was not final. Over the course of the months the problem of: "*What is she going to do for us*?" re-emerged several times. It led to further meetings where I had to re-affirm that I could not bring them direct benefits. These, though, were isolated cases, that were perhaps driven by the fact that previous researchers had brought them benefits (even if indirectly), so there was the expectation that I could do the same. Most farmers accepted my role as a student and I became a familiar sight, visiting the farms almost every day, a fact that elicited some degree of surprise and admiration at my commitment and perseverance. Relations passed from formal to friendly, particularly with the younger farmers, and this was critical to my work. Even if the farmers did not understand what I was doing and why I had to do things in such a strict way, they did their best to be helpful, so that I could collect the best possible data. Where I or my field assistant had not succeeded in forging a good working relationship, the quality of the data was poor, and this has to be borne in mind during data analysis.

My age (and that of my field assistant) played an important part in the type of collaboration I obtained from the farmers. Although some individuals felt that I must have connections and influence, others readily accepted that I was a student because I was young. This made them more willing to share information, and the older farmers particularly took on a benevolent 'teacher' role. The downside of this was that there was no scope for debate or discussion of ideas as they were the 'teachers' and I was the 'student'. Relations with the younger farmers were difficult initially because they were distrustful but once they had been established, they were on a more equal footing. The friendship prompted them to be more flexible and ensure that I obtained good field trial data, and also I could challenge established notions without offending them. This could lead to fruitful discussions.

4.6.2 The role of the field assistant/interpreter

I had to employ an interpreter because there was a language barrier that prevented me from communicating directly with the farmers. This made me realise how critical a good interpreter can be and, in retrospect, I would say that issues of positionality are as important or perhaps more important for the interpreter than for the foreign researcher. I employed a graduate from the University of Jos, and initially I had been very concerned about the issue of ethnicity, religion, age and gender (as most farmers in Delimi are Hausa Muslim and there are no female farmers). I believed it was more suitable to use a male interpreter and I would have preferred a slightly older man, as Nigerians attach great importance to age, equating age with wisdom. For this reason, I was slightly hesitant because my field assistant was in my age group and additionally was a Yoruba Christian. On the other hand, I knew that it would be difficult to find an older man who would work for me full time and have sufficient schooling to interpret skilfully. I felt that ethnicity and religion were not such a large barrier as I initially feared, probably because the interpreter was being introduced to the farming community by the respected *shugaba*, who, in turn, accepted the interpreter because the University lecturer had introduced him. Friendly relations were established, despite my field assistant's ethnicity and religion. However, I cannot exclude that his ethnicity did not prevent him from understanding some particular cultural features. For example, there were times during his discussions with the younger farmers that he would urge them to take innovative steps in solving certain problems, but he would be confronted by general apathy (see sixth discussion point under 4.6.3). Age was a different matter, because like me (4.6.1), his youth facilitated the establishment of friendly interactions with the younger farmers, but promoted teacher-student relations with the older farmers.

I was surprised to find that although it was clear that the interview information was for me and not for him, in many instances farmers talked to my field assistant as if he were the researcher. In fact, for many months I almost felt 'invisible' and 'left out'. In reality the farmers' reserve was predominantly caused by shyness, rather than unfriendliness, and in time we developed a friendly banter with the little Hausa I had learnt, which helped dispel my sense of isolation. In fact, I eventually discovered that a few of the younger farmers spoke more English than they were willing to admit at first, and as they got to know me they overcame their shyness and started addressing me directly in English, rather than go through the interpreter, as they had done in the beginning.

The style of interviewing was something that I had to negotiate with my field assistant. I trained him in what I wanted from the interviews and this took a little time. For example, I sensed that I was receiving the condensed versions of the discussions with the farmers and only the information I had specifically asked for. After a couple of discussions, my field assistant realised that it was important that he translate as literally as possible, and report any statements that were unconnected to the question, so he corrected his way of translating. On the other hand, I had to concede that the interview could not always proceed in the way that I thought suitable. I wanted him to translate questions as literally and directly as possible, and it was a while before I accepted that a fast and direct question, that is appropriate in English, could be interpreted as rude in Hausa. We eventually compromised that where a preamble was necessary, it should be formulated in a neutral fashion so as not to 'hint' at the answer. I also had felt that my field assistant should translate regularly as I feared that in the summary I might miss something of importance, but in some instances this would have been impolite. For example, we realised that even if farmers had finished answering my specific questions, they might want to continue discussing other matters, and interrupting them to translate my specific questions could be counter-productive. My field assistant had to judge if there was a suitable pause to translate, or else we would have to wait until we had left the farmer's field.

After several months I came upon an unexpected hurdle. I discovered that farmers who had already been interviewed once or twice, had tired of being formally interviewed, and even if we were on good terms, they expressed their dissatisfaction at my continual questions. Although I continued with formal semi-structured interviewing with new farmers (i.e. my interpreter would ask a question, translate the answer, and I would record the answer in my notebook before moving on to the next question), I had to abandon this mode of gathering information with farmers who knew me, if I wanted additional information. I resorted to giving my field assistant a list of questions in advance and getting him to engage in a prolonged discussion and recording the answers only once they had finished. The farmers did not seem to object to this way of sharing information. Of course, it meant that I had to rely on my interpreter to memorise the answers but generally this method worked well.

Overall, my field assistant played a critical role in information gathering. There was a language barrier for me, so his personality and his persuasiveness were what convinced the farmers to be interviewed or co-operate in the field trials. I realised that it was important to engage in a dialogue with him during the training process, so as to highlight the most important notions of interviewing, but to also be receptive to his suggestions that came from his deeper knowledge of the cultural background. Certainly, the key to obtaining good information in my research turned out to be the selection of someone with good communication skills and a good attitude.

4.6.3 Farmer participation

During the conception of the thesis I realised that a successful field trial had to include the farmers' input, otherwise it would lack realism and this would jeopardise the acceptance of the results (see Chapter 1 for explanation of original thesis intentions and part of 4.2.4). I examined the literature for the various participatory techniques, and decided to adopt those that seemed most suitable to the circumstances. Therefore, I set out to include the farmers at the design stage of the field trials.

I explained my intentions to all involved. The *shugaba* approved and even volunteered his land. The elders at our first meeting approved the research and told me that I was welcome to pass through their land, speak to them and take samples. I then explained the research to potential collaborators who expressed an interest and stated that they would be willing to let me take soil samples and would be happy to discuss their activities with me. And yet, although all agreed to co-operate, none took an active interest in designing the field trials. One farmer did agree to run different trials on a sizeable portion of his land but later backed out because he wished to rent the land to one of his neighbours. Even so, although he had agreed to apply certain combinations of fertiliser, he did not actively take part in deciding what the trials should consist of. A younger farmer provided a lot of feedback on how the trials should be run. He pointed out that if the trials were run on a single farm, they would be relevant to that particular soil type but not another farm. He explained that if I wanted the trials to be truly successful, I needed feedback from many different farmers and not just one man, because each had his particular strategy. He also added that I needed to ensure that if I worked on just one farm, as well as the fertiliser treatment from outside, I needed to adopt the general management strategies (quantities of fertiliser, weeding, watering, etc.) connected to that particular fertility treatment. Yet, despite his feedback, he refused to collaborate unless he was to receive material benefits for his co-operation. Every other farmer explained that he had his own strategy that was the most suitable for his land, and did not volunteer new alternatives.

This experience made me decide to monitor different farmers' strategies, take soil samples and not interfere (4.2.4). I felt that a monitoring approach would be more realistic, and perhaps useful, than artificial field trials where I alone set the conditions. Field trials would have been useful if the farmers had been actively interested in their outcome. As it turned out they were willing to co-operate but not participate.

I have tried to understand why farmers were not interested in participating. I have come to several hypotheses but I am unsure which factor(s) played the greater role. Probably different combinations worked for different farmers. I feel that a primary reason for the lack of enthusiasm consisted in our differing agendas. As a PhD student who sought to carry out a 'practical' research project, it was necessary for me to choose a particular aspect of farming and consider different ways of implementing field trials, involving the farmers at the design stage. The constraints of a PhD are such that I could not have built sufficient flexibility into my research plan so as to radically change its course, if necessary, and be sure of collecting sufficient data to complete the PhD in the three-year time frame. This does not mean that I did not make changes to my research plan. Clearly I did, but I could not totally change the focus of my thesis. I had chosen to investigate soil fertility and the different ways of recycling urban waste as a fertiliser. I had trained in this area, and I had to remain in it, even when I realised that the interviews were yielding the impression that farmers were not really interested in soil fertility or not really interested in further research, because they thought they had developed the best possible fertility strategy for their land. Each farmer was aware that there were differences between soil types and, consequently, had devised a soil fertility treatment to meet the requirements of his particular land. Therefore, research that suggested testing alternatives using different combinations of fertilisers they had already experimented with was not going to be met with enthusiasm, if they believed that they had tried everything and discovered the optimum approach.

Secondly, I also think that I did not have sufficient time to convince farmers to participate. Various authors have remarked that it can take months or years before a development worker establishes a climate of trust so that the farmers agree to participate (Okali *et al.*, 1994). For example, in the second phase of the Indigenous Soil and Water Conservation programme (ISWC 2), it was expected that scientists, extensionists and farmers would begin joint experiments by the end of the first year of the project. In reality, joint experiments began in most countries only in the third year (Reij and Waters-Bayer, 2001a). In my situation, I had very little time. I met a few of the farmers in early September, towards the end of the rainy season (most did not arrive until early October), and sampled from my first farm in late October. Although I was being introduced through someone who had brought researchers to their area before (and who had brought benefits), I was a stranger and they were not disposed to provide their full co-operation for someone who they did not know and whose agenda was unknown. Although I did eventually identify truly interested or benevolent farmers, by this time I had had to adopt a research strategy for the farming season.

Thirdly, there was conflict in the scale of the experimentation. My field trials required large tracts of land (relative to the land that the farmers possessed), perhaps 15-20 subplots, and it is generally established that when farmers experiment, they do so on a very small scale, with little or no replication. Some agencies suggest that to overcome this obstacle, what is important is replication *across* farms, not replication *within* farms (Werner, 1993). Yet, because soil variability is such a significant factor in any fertility project, it is untenable to set experiments on one or two sub-plots per farm only, when soil analysis is one of the techniques used in the project. The requirement for extensive land discouraged several individuals, as they could not afford to risk crop failure on such a large scale.

Fourthly, farmers were beset by other problems that put their activity at risk in the short-term (8.1), so that even if they were aware of the threat of soil degradation, they could not afford to prioritise it. Hence, a project that was concerned with soil fertility was unlikely to arouse their interest. I understood that even if soil fertility was a real problem, unless their most urgent concerns could be addressed and resolved first, they would be unwilling to put any effort into a problem that was not immediately worrying them.

Fifth, it was possible that farmers felt discouraged by the lack of governmental support, so they were unwilling to participate because they did not believe that anything would change.

On a number of occasions, when farmers were approached for an interview their reaction was very negative, and several explicitly asked why they should sacrifice their time, when they had discussed the same issues with previous researchers and nothing had ever changed (4.7.2). These feelings were so strong that they may have also determined the lack of enthusiasm in the field trials.

Sixth, and finally, I reflected on the significance of two cultural issues. On the one hand there is a general lack of formal education. Amongst the Hausa people there is a tendency to invest in the schooling of a few children, who are then expected to obtain a white-collar job, and certainly not return to full-time farming. Those children who are expected to become farmers are not sent to school (Jasper Dung, Pers.Comm.). In the study area, 48% of farmers have received no formal education, 27% have received Koranic education and the remainder have received either primary or secondary school education (Pasquini *et al.*, in preparation). Could this have hindered their participation? Most farmers did not understand what they were applying when they used IFs and their strategies were empirically derived. They did not particularly understand that there could be better ways of using IF, and reduce waste. Nor did they realise the potential health risks attached to the use of urban waste-derived ash. Perhaps a basic education would have helped them understand the potential of the research, although some research has found that there is no significant correlation between the level of formal education and the innovativeness and tendency to experiment of farmers (Reij and Waters-Bayer, 1992b). On the other hand, I considered the influence of the strict age-related hierarchy amongst the farmers. I felt that, in some situations, younger farmers had interesting ideas, and the ability and interest to learn new concepts. And yet, they would not participate or take an active role in trying to resolve some of their problems. My field assistant would sometimes ask why they did not form associations and pressure groups to try and resolve common problems, but the reaction of the younger farmers would be to shrug and change topic. I wondered if the social hierarchy prevented the younger farmers from introducing bold changes into the farming community. Certainly, I found that, although I requested that all farmers should be invited to the general meetings, consistently the younger farmers were never informed about them. Even if they were aware of a meeting, they never attended, only the elders were present and made decisions. It is likely that this is an important issue, as it has been shown that in other settings, the social organisation of different age groups is a significant force that determines the number of innovations practised in the area (Nielsen, 2001).

4.7 METHODS FOR INVESTIGATING SFM STRATEGIES AND BROADER FARMING PROBLEMS THAT AFFECT FARMING STRATEGIES

As introduced in 4.1, this section discusses the approaches to gathering 'social science' information that have to be merged with the 'natural science' data collected in previous sections, to place the outcome of the monitoring field trials into a wider farming context. This section predominantly collects information relevant to aim 1 (although as already mentioned at different stages, some of this information has been used to provide a better appreciation of aim 2 and 3) and aim 4. Aim 4 has a lot of relevance for aim 1, as the appropriate management of soil fertility hinges on farmers being able to find solutions to short-term problems. The next paragraphs will particularly describe the methods used to collect information for objectives I and VII. In addition, some of these methods were used to collect information to create a background to the farming system (most of this was used in Chapter 3). In summary, this section describes the data collection process for:

1. General farming practices (cropping patterns were particularly intriguing because they had not been investigated thoroughly: the information gathered has been presented in Chapter 3, as background to the farming system).
2. SFM practices both in the Delimi area and in Rayfield. The Rayfield area was studied because it is a very large peri-urban production area, characterised by different farming scales (farms on the whole are larger), crop specialisation, and road access (farms are remote, but easily accessed with a vehicle). It was likely that farmers in Rayfield would have different needs, which would provide a different outlook on the maintenance of soil fertility, and the constraints to obtaining fertiliser.
3. General farming problems. It is essential to understand how farmers perceive and rate their problems, because this provides a framework on how they rate SFM problems. It also allows a more realistic assessment of whether the thesis' recommendations could be accepted/adopted by the farmers.
4. The perceptions of farming problems by various formal organisations that were linked in some way to dry season farming activities (such as PADP, FUA and JMDB), to contrast and compare them to farmers' accounts of their activities and their problems.
5. Miscellaneous information that was used in the discussion in later chapters.

4.7.1 Dry-season irrigated farming survey

Information on the general characteristics of dry-season irrigated vegetable farming was collected by survey. The 2000 survey was a collaborative project (that was distinct from the research work for this thesis) between Harris and Pasquini from the University of Durham, UK, and Adepetu and Dung from the University of Jos, Nigeria, which fell under the auspices of the University of Durham-University of Jos linkage project, sponsored by the British Council between April 1999 and March 2002.

The DSIVP survey took the form of a questionnaire survey. This was done for two reasons. A questionnaire survey has the advantage of obtaining a lot of information quite rapidly and obtaining the same type of information from many individuals. All this information can contribute to a general description of the subject under investigation and define its broad characteristics. So, the first reason for using the technique of a questionnaire survey was to provide the backdrop for the thesis. The second reason for conducting a questionnaire survey in 2000 was so that information on changing farming practices could be gathered: in the 1980s and the 1990s the Delimi River farming area had already been surveyed (Adepetu, 1985; Phillips-Howard *et al.*, 1990), thus a new survey would provide data on the changes in the farming system over a period of 18 years (from 1982 to 2000). The third reason was that the questionnaire could be administered in four different areas (Delimi, Rayfield, Korot and Barakin Ladi)[8], to determine the spatial differences in dry-season vegetable farming. The survey was administered in December. Delimi was chosen because it was the field site of the thesis and also because a temporal analysis could be carried out. The other three areas were chosen by recommendation of Adepetu and Dung. Rayfield and Barakin Ladi were already being farmed in 1982 and, in fact, had already been surveyed by Adepetu (Adepetu, 1985). In 2000, they represented two major production areas. Korot was another important production area of relatively recent origin. The questionnaire was administered by four trained field assistants and was piloted in a small farming area along the Delimi River to the south of Langalanga (i.e. closer to the built-up areas in Jos).

The 2000 questionnaire was modelled on the questionnaire developed by Adepetu in 1982 (Phillips-Howard *et al.* (1990) maintained the same questionnaire, so that the results could be compared for the Delimi area). It differed from the original by the addition of questions on fertiliser and pesticide use and problems faced by the farmers. These questions were included in the 2000 survey because they were directly relevant to the thesis. The 2000 questionnaire consisted of 37 questions covering farmer characteristics (age, experience in farming, family structure, educational, and occupational background), land tenure, irrigation practices, farming inputs, market-related issues, farming-related problems (see Appendix A).

A section of the questionnaire requires some in-depth explanation. In order to calculate a general rate of fertilisation, it was necessary to obtain farmers' estimates about amount of IF used over the whole season and calculate the size of the total farming land in all areas (Appendix A). As farmers are frequently not aware of the real size of their land (Phillips-Howard *et al.*, 1990), it was necessary to measure each farm. Direct measurements with a tape-measure would have taken too much time so an alternative method was adopted: the surveyors

[8] Delimi was covered by 52 questionnaires, Rayfield by 49, Barakin Ladi and Korot by 50 each. This gave a total of 201 questionnaires for the whole survey project.

were asked to count and record the number of subplots in each farm. In such a way the total farming area surveyed could be estimated by multiplying the total number of subplots (data not shown) by an average subplot area value. With this method the estimated total area for 52 farms in Delimi is 11.7ha[9].

Rayfield farms were far larger than farms in Delimi, probably because of the flat terrain, which facilitates irrigation. Time constraints and problems with the surveyors did not always permit direct counting of the subplots for the larger farms. Thus, farm size in Rayfield was estimated in two ways, either by recording the farmers' estimate in hectares (22 farms) or by counting number of subplots in the farm, if the farmer did not know the size of his land (27 farms). The final estimate for farmed area should only be considered an approximate guideline because of various sources of error: farmers who gave their own estimate would not necessarily know the precise size of their land (Phillips-Howard *et al.*, 1990, found that this was the case for farmers in Delimi), and the subplot area value used to make a direct estimate. With these two methods, the total farming area for 49 farms in Rayfield was estimated as 86.8ha[10].

4.7.2 Semi-structured and unstructured interviews in the field: Delimi

The fieldwork period began in late September with preliminary semi-structured interviews on the general SFM strategy (4.2.3). Interviewing continued with other farmers even after the methodology for the soil sampling project was established, because each interview continued to yield interesting information on the use of organic and inorganic fertilisers. All interviewees were male, and the farmers interviewed were not selected in any systematic way: any new farmer encountered during the day was approached, and if willing, interviewed. With few exceptions the interviewees were Hausa, and their ages ranged from early 20s to 70s-80s. Response was close to 100%, as even farmers who initially refused an interview changed their opinion after some discussion with the interpreter. It was observed that the negative response was usually a result of the general frustration of the farmers towards the lack of support by the government, and the feeling that they had collaborated with several interviewers in the past but never experienced any benefits. The farming area was explored thoroughly (moving approximately in a south-north direction from the University Staff Quarters), by following the access paths that ran along both banks of the Delimi River. After 25 interviews, it was apparent that saturation point had been reached, and as a sufficient body of farmer knowledge had been gathered from the farmers, it was better to devote time and resources to a different topic.

[9] In Delimi this value was calculated using an average subplot area of $3.84m^2$. This was derived from the estimated average values of six farms. Fifteen to twenty subplots were measured for six different farms. The average subplot areas for the six farms were $2.88m^2$, $3.60m^2$, $3.65m^2$, $3.76m^2$, $3.89m^2$, $5.27m^2$.

[10] Subplots in Rayfield were not measured directly, but as they were observed to be larger than subplots in Delimi, it seemed reasonable to use the maximum subplot area value found in Delimi (i.e. $5.27m^2$) to estimate the area of those farms that were measured by subplot counting.

During the conception of the whole thesis, a list of secondary interesting issues for the interviews had been identified. The general discussions with the farmers on a one-to-one basis clarified which topics should be pursued and which should be discarded. Initially, the soil classification system was considered an interesting subject, but preliminary questions revealed that it was not going to be a very fruitful topic because only a few of the older farmers seemed to be knowledgeable about soil classification. Most farmers claimed to know little about the properties of different soils. Instead, during the interviews, farmers were spontaneously talking about the various problems that they were facing, and it became obvious that without an understanding of their most urgent problems, it would be difficult to ground their perceptions of long-term soil fertility maintenance. Thus, general problems in farming became a priority topic for the interviews. Once this topic was addressed, the interview focus shifted to cropping patterns, because soil fertility maintenance and IF recommendations are linked to the type of crops grown, and this topic has not been explored in any great detail. Information on cropping patterns from the interviews could also be merged with the information collected in the survey (4.7.1). The interviews on farming problems and cropping patterns were partly conducted with farmers who had been identified as 'key informants' during the first interview and partly with new farmers. Once more, the new farmers were selected if they were encountered on their farm on the day of the interviews, and if they were willing.

The interviews had to be conducted in Hausa as few farmers spoke English. Some of the younger farmers appeared to understand the formulation of the questions in English, probably because they spoke basic 'pidgin' English, but they always responded in Hausa. In a couple of cases, though, it was possible to conduct the interviews in English.

Details about the field assistant/interpreter's training have been provided in section 4.6.2. Part of the training consisted in reviewing the early interviews, after work, and discussing the problems of literal translation. This improved the quality of the interviews, as the field assistant learnt from experience which was the best way of introducing the research to a new farmer, how to manage and appease hostile farmers, the best way of formulating the questions, and to translate all information in the ensuing discussions, relevant or irrelevant. Questions were formulated in a neutral manner without prompting the response of the farmer and answers translated as literally and comprehensively as possible. It was not always possible to translate a question from English to Hausa in a direct and literal fashion because of the different structuring of the language. Certain concepts that exist in English do not have a Hausa equivalent (and *vice versa*) and have to be adapted. Furthermore, allowances have to be made for the cultural context: English, as a language, tends to be quite straightforward and direct, questions and statements can be formulated in a terse fashion (and it is often preferable). In Hausa this could be considered rude and unfriendly. Especially where an unfamiliar concept had to be translated, the interpreter felt that it was necessary to explain things at length and colour the explanation with examples.

4.7.2.1 Topic: SFM strategies and the role played by ash in the system

Twenty-five male farmers of differing ages (out of 50-60 in the whole farming area) were interviewed on the use of inorganic and organic fertilisers, with particular questions on the reasons for applying ash (see Appendix A). The semi-structured approach was adopted so that while all matters of interest were addressed, the freedom to pursue any interesting side-issues was maintained. First, the purpose of the thesis was explained to each farmer and his consent to be interviewed was sought. If the farmer consented, he was asked to explain specifically which combinations of fertilisers he used (both organic and inorganic), how, how much, and in what order he applied them, if and why he used ash and how he obtained the ash. The more talkative and friendly respondents often contributed spontaneous and partly unrelated information, which sometimes opened up new avenues for questions. All information was recorded, even if it was unrelated to the actual interview topic. These respondents were questioned very thoroughly on their understanding of inorganic and organic materials and were noted as potential key informants.

4.7.2.2 Topic: General problems in farming

During the interviews on fertiliser use and other general discussions, the farmers often took the opportunity to mention the difficulties they had to face in their enterprise. It became clear that this topic needed to be explored in depth to define the farmers' priorities. If farmers are faced with problems that threaten to put them out of business in the short-term, they will not be receptive to the issue of long-term decline in soil fertility.

In all, 17 male farmers of differing ages (out of 50-60) were interviewed about their farming problems (see Appendix A). These comprised some of the farmers who had already been interviewed on SFM strategies (the friendliest and most informative), whereas the remainder were new respondents who were located further north along the river. The interview style can still be considered semi-structured, even though the questioning was a lot more open than the previous set of interviews. All interviews commenced with the question "*What type of problems do you face in your business?*", and the remainder of the interview depended very much on the response of the farmer. Some farmers presented their difficulties in a very detailed and coherent manner and were only interrupted for further clarification. Other farmers were less able to expand on their problems and had to be prompted with open-ended questions such as "*What about the market?*" or "*What about farming inputs?*". A few individuals were obviously quite reluctant to be interviewed even though they had given their consent, so these interviews were limited to the information they disclosed immediately and were concluded quite swiftly. It is probably a cultural characteristic to be polite to strangers and to agree to help, by being interviewed, even if there is no wish to be interviewed. In fact, on no occasion did a farmer decline to be interviewed in the Delimi area (although they did in the Rayfield area—4.7.3). Even those who refused initially and explained vehemently why they did not want to be interviewed, eventually calmed down and changed their minds. Other farmers assented with no discussion but their hostility was so clear that the interviews were unproductive.

4.7.2.3 Topic: Cropping patterns

The final interview topic concerned cropping patterns (in all 14 male farmers of differing ages were interviewed, out of 50-60 in the whole farming area—This information has been used in Chapter 3). These interviews were completely unstructured as they were based on the first question "*What are your motivations for mixing certain crops together?*" (see Appendix A). Usually, the field assistant also pointed out different portions of the farmer's land with statements such as "*For example, over there you only have lettuce but here you have spinach, lettuce and cabbage*". The farmers then were free to answer as they wished, and most listed or pointed out their various combinations and explained their motives. They were never prompted with the answers, unless they had not been particularly informative, in which case they were asked if there were any other reasons. The only other time when questions were put to them was if something was unclear and needed further explanation.

4.7.3 Structured interviews in the field: Rayfield

The Rayfield area is a very extensive area that is located on the south-eastern boundary of Jos. It consists of several sub-areas that are accessed through different routes and have different characteristic features. One area, for example, comprises land that has been designated for urban development. Indeed, all of the land has been sold to various people who plan to build on site in the near future. Here, farmers rent the land from the owners but their position is very precarious as they could lose their land at short notice. Another area was formerly mining land and is characterised by open-cast paddocks that have become ponds. This area is flat and open, and easily accessed with a vehicle but it is quite far from the built-up area.

Rayfield was one of the areas included in the survey (4.7.1), and analysis of the data on fertiliser use showed that the farmers claimed to use a lot of ash and poultry dung. This finding was compared to the outcome of the survey in Delimi and, as both these areas are located on the peri-urban fringe of Jos, it was important to establish why one area appeared to use organic materials in such large quantities compared to the other. Thus, 18 male farmers from various locations were interviewed on their use of ash and animal manure. Farmers were selected on the basis that if they were encountered on their farms during the field visit they were approached and if they consented, interviewed (response rate was good, but a few individuals declined to be interviewed). The interviews were structured and were based on eight questions (certain answers of course precluded further questions— see Appendix A) and were conducted by two people, Mr Dung (from Department of Geography and Planning, University of Jos) who used either Birom or Hausa and Mr Olaniyan (the field assistant/interpreter) who used Hausa. One or two farmers preferred to be interviewed in English.

4.7.4 Observation and recording of information

Observation is an obvious way of obtaining information. To gain familiarity with the farming system, farmers were observed during their work and novel activities were noted. If something was not clear, farmers were asked to explain what they were doing. Very often a comment on a particular activity would open up a discussion that would lead to other information. Everything was written down: observations, comments, even apparently unrelated subjects of conversation.

Apart from using observation as a learning process, observation was also used to corroborate statements made previously by the farmers, but also to collect background information before initiating a new topic for discussion. For example, cropping patterns were investigated first by recording and counting the types of combinations observed on the farms of different people and later by interviewing farmers on cropping patterns (see 4.7.2.3).

Observation refers not only to a straightforward process of looking at and describing something, but also refers to being aware of non-verbal cues of the people being interviewed or of farmers attending a meeting. These cues are important to try and determine the veracity, or perhaps, the degree of exaggeration in the information given out, as well as the 'mood' of a group of people. Observational data have been used to support the discussion of results in Chapters 5, 6, 7 and 8.

4.7.5 Visits and interviews in various locations

A final method to confirm information given out by farmers consisted in paying visits and conducting formal interviews or informal discussions with representatives of different organisations. Local markets and specialised shops were visited to obtain information on prices and availability of farming materials, whereas the Plateau Agricultural Development Programme (PADP), Fadama Users Association (FUA) and the Jos Municipal Development Board (JMDB) were visited to obtain official accounts of aid given to dry-season farmers.

4.7.5.1 Local markets and shops

Local markets were visited on several occasions for different purposes. An inventory of different chemical fertilisers available was compiled by examining different stalls, and by visiting the official IF depot which is located just outside of PADP's headquarters. The vendors were also asked to measure out a *mudu* of each IF so that it could be weighed with a bucket and spring balance (see 4.2.8). Prices of seeds (and types available), pump engines and agro-chemicals were also investigated.

4.7.5.2 Plateau Agricultural Development Programme (PADP)

PADP is a state-run department that was set up for the purpose of educating and advising farmers through extension agents, and providing good-quality farming inputs (seeds, pesticides, farming implements). The headquarters of PADP were visited on two occasions. The first occasion was rather informal, so that an inventory of official seed and chemical pesticide prices could be drawn up. The second visit was a formal event where three representatives were interviewed but, for reasons of anonymity, their names and Departments are not reported. The representatives discussed the role of PADP and generally introduced the purpose of their particular section and responded to questions. They also gave information about the origin of FUA and the National Fadama Development Facility project.

4.7.5.3 Fadama Users' Association (FUA)

FUA is a farmer-based organisation that was created for the purpose of dividing farmers into easily identifiable groups to promote the development of '*fadama*' farming. The origins of the FUA are unclear as the farmers and testimony of people from the University claim that it was created in the early 1990s under suggestion from the PADP, who would not otherwise deal with the farmers. PADP claim that its creation did not occur officially until 1997 when a World Bank project required an official farmer body. The Chairman of FUA was met on two occasions, and during these meetings he discussed the role of FUA and the problems experienced by the farmers. The final visit to the headquarters of FUA occurred May 2001 on the occasion of the official launching ceremony of the new FUA market.

4.7.5.4 Jos Municipal Development Board (JMDB)

JMDB is concerned, amongst other things, with waste disposal. It services the areas called Jos North and Jos South. Rayfield falls under the jurisdiction of the equivalent body in Bukuru. The interview with a JMDB official served the purpose of gathering information concerning the practices of waste disposal in Jos, the resources available to perform this task, and the official position on the issue of waste utilisation by peri-urban farmers. This information could then be related back to the observed practices of urban refuse utilisation in agricultural areas and to the interviews with the farmers.

5 SOIL FERTILITY MANAGEMENT STRATEGIES IN PERI-URBAN JOS

The assessment of the effects of the expansion of DSIVP on soil fertility has to begin with the examination of current SFM practices. Phillips-Howard and Lyon (1994) reported that farmers had developed a highly successful SFM strategy, which had locally raised the fertility status of the soils. However, the rapid expansion of DSIVP (Porter *et al.*, 2002) could have led to changing socio-economic circumstances, which would push farmers into changing their SFM practices and this, is turn, could jeopardise the stability of the farming system. In order to achieve objective I, the following research questions have been identified:

1. What is the rationale behind current SFM practices?

    a. What are the characteristics of current fertiliser practices in Delimi?
    b. What are the characteristics of current fertiliser practices in Rayfield?
    c. What are the fertiliser application rates in both areas?

2. How do today's SFM strategies compare to the past?

3. Are any trends for the future emerging?

In order to answer these questions, farmers were interviewed about general SFM practices in two locations, Delimi and Rayfield. Information pertaining to questions a, b, and c (which has been presented in section 5.1, without discussion) was primarily collected to address the first question, although of course this information is relevant to questions 2 and 3. The three major questions are discussed in sections 5.2, 5.3 and 5.4. The use of urban waste ash has partly been reported on here, but further detailed discussion of this topic will be in section 7.2.

5.1 GENERAL FERTILISATION PRACTICES

This section summarises the main points emerging from the interviews on SFM and presents data on fertiliser inputs in both Delimi and Rayfield, obtained with the survey described in 4.7.1.

5.1.1 SFM strategies in Delimi

Semi-structured interviews (25 in all) revealed that there are as many fertiliser strategies as there are farmers. In many cases, it became evident through observation that the strategy discussed during the interview was based on an ideal situation, as logistical reasons could prevent a farmer from using the desired inputs (see case study examples in 6.3.3). Nevertheless, there are some common features in the fertilisation practices and a pool of information that is shared, to a certain degree, by all the farmers.

1. Farmers make a distinction between traditional (*takin gargajiya*) and modern (*takin zamani*) fertilisers (Phillips-Howard and Kidd, 1991). Inorganic fertilisers belong to the latter category, whereas livestock manure and waste ash are classified as traditional fertilisers.
2. All farmers apply fertiliser in multiple stages. During the first half of the season up until the first major harvest they will apply fertiliser from two to four times, depending on their preference and the crop planted. They will fertilise again in the second half of the season, when they have planted new crops, but they will reduce the number of applications, as there is residual fertiliser left over from the first half of the season.
3. All farmers rely primarily on IFs, even though most will combine them with either waste ash or animal manure. A general consensus is that IFs will result in fast crop growth but will not remain in the soil for very long, whereas traditional fertilisers act slowly but are persistent and their effects can be observed for several years after application. Some farmers observed that exclusive application of IF, in the long term, would 'ruin' the soil (by making the soil 'hard' and very difficult to work. Ash by contrast softens the soil). Others had observed that IF, especially urea, would dry out the soil.
4. With few exceptions, the farmers will purchase several types of IF and mix them together in specific ratios. It is rare that a farmer will rely on just one type. Each farmer has his favoured combination but the reasons for choosing to mix urea and super-phosphate, followed by NPK 15:15:15 and urea, rather than use a single mixture of NPK 15:15:15, urea and super-phosphate in several rounds, are not clear. It is probable though that farmers can detect that the NPK 15:15:15 is not appropriate for all crops. Urea was recognised to be particularly effective for spinach.
5. Overall, the majority of farmers are not aware of what they are applying when they use IF. This was particularly noticeable when farmers chose to mix different brands of NPK 15:15:15 (called Golden, Kampa or 15-15 by the farmers), because of a perceived difference between them. This difference could be an imagined one (based on the aspect of the IF: Golden NPK 15:15:15 is white, Kampa NPK 15:15:15 is red and Plateau State NPK 15:15:15 has multicoloured grains, white, red and gray), or perhaps it is real (even if the ratio is correct, the source may be different). One farmer who was aware of the nutrient content of the various IFs and knew that NPK 15:15:15 contained the nutrients in a balanced ratio, commented that he had observed differences between brands. Furthermore, some farmers complained that IFs did not seem to be as strong as they used to be.
6. Most farmers feel that the best results are obtained with a combination of IF and traditional fertiliser (mostly ash). They expressed this in various ways: one stated that "*Inorganic fertiliser is to ash (for crops), as food is to water (for humans)*"; another said that "*Inorganic fertiliser makes the roots do well and the ash makes the leaves do well*"; another

still said that "*Inorganic fertilisers enjoy the company of ash*"; many stated that the two had different, complementary roles.

7. Organic fertilisers are considered to have various advantages: they reduce the need for IF (by up to half the amount); they make the soil 'soft' allowing the crop to spread its roots; they are persistent. The main disadvantages are: the increasing cost; the large amounts needed in comparison to IF; the slow response of the crops.
8. The farmers put great importance on having dark green leafy crops, for marketing reasons (a dark green vegetable is more attractive to the buyer). Most thought ash was responsible for the change from light green to dark green (see Figure 5-1), but a few thought that the more intense colour was caused by the application of super-phosphate or by the mixture of NPK, urea and super-phosphate together.
9. Most farmers confirmed that the amounts and type of fertiliser they have to apply depend on the crop they want to grow, and also on the type of soil they are growing the crops on. They also knew that certain soil types were suited to some crops but not to others.

Figure 5-1: Carrot crops with (right hand photo) and without (left hand photo) ash application (note deeper colour of those with ash)

5.1.1.1 Problems related to ash acquisition and use

The interviews collected detailed information on the mode of action of ash. This information has been presented and discussed in 7.2. Here, only the problems related to ash acquisition and use are reported.

A survey in the early 1990s had shown that the use of ash and animal manure was quite widespread in the area. This was linked to the declining availability of IF (Phillips-Howard *et al.*, 1990). Observation of the activities in the farming area in 2000/2001 showed that despite the recognised benefits of ash and the professed intention of using it, very few farmers actually used it that season. A few farmers made their own ash from debris brought by the river on the floodplain during the rainy season, others produced ash from farm waste. Only a couple requested a tipper-load of refuse from town. Various explanations for the observed decline in the use of refuse ash can be advanced, although the possibility that the decline can be attributed to circumstances affecting that particular season only cannot be excluded entirely. For example, one farmer explained that the demand for refuse ash depends on the year. When IF is readily available the demand for ash is lower than in years when IF is scarce (in 2000/01 there did not seem to be a scarcity of IF). This opinion, though, did not seem to be shared by the majority of the other farmers.. If a farmer had money, he could easily purchase IF.

1. Ash can be obtained from the JMDB, who will bring a truck-load of refuse for 200 Naira. This can be compared to the cost of a private pick-up load of refuse (about 600 Naira), or a pick-up load of ready ash (600 to 1500 Naira). Still, farmers complained that refuse was no longer freely available: its availability depended on the town council, who would frequently prefer to bring waste to large-scale farmers, who could afford to pay more for it. Furthermore, there was confusion over who was responsible at JMDB. Some stated that the arrangements were made informally with the actual truck drivers, others thought that it was necessary to go to the central office to order a truckload, and others thought the chief of the farmers was the go-between.
2. A visit to JMDB revealed that, at the time of the research, there were only four operative trucks remaining from the original 23 that were commissioned to service Jos North and Jos South (Appendix C). This situation will certainly limit the number of trips that can be made to the farming areas with town refuse, and, consequently, the number of farmers receiving a truck-load.
3. One farmer said that the JMDB trucks were no longer encouraged to bring refuse to the farming area because they had to drive through University Staff Quarters and the residents had lodged a complaint.
4. Another farmer complained that wood ash was becoming very scarce as people were cooking less frequently over wood fires.
5. Some farmers were dissuaded from obtaining a load of town refuse because it was frequently full of plastic and bottles, and so it was not worth the expense and the labour to prepare and sort the ash. They also have to put a lot of labour into transporting the ash to their farms because there are no access roads, so the JMDB trucks are only able to transport the waste up to a certain point, and this is convenient for only a few farms.
6. Ash may also be less commonly employed because it is slow-acting and market pressures force the farmers to obtain fast growth, so they favour IF. Even more simply, farmers may prefer to headload small amounts of IF, as the Farin Gada market is accessible by footpaths.

5.1.1.2 Use of livestock manure

Livestock manure was not mentioned very frequently during the interviews. In most cases, specific questions had to be formulated to obtain information, as farmers did not seem to consider it very important. In comparison, information about IF and ash was elicited very easily.

Figure 5-2: A heap of cattle manure used by a Delimi farmer

1. Frequently the farmers stated that they did not use or no longer used livestock manure. Their main reason was that it was difficult to obtain: it was scarce and it was expensive. This had occurred mainly because of the changing status of the Fulani. Fulani pastoralists had traditionally followed a transhumance system that brought them to the Plateau during the dry season. They needed regular access to watering points and rangeland, which was being increasingly curtailed as irrigated farming expanded (Porter *et al.*, 2002). As a consequence of having to decrease livestock numbers, less manure was available. Some farmers would have preferred livestock manure to any other form of fertiliser but found that it was so scarce that they could not rely on it. Poultry manure tends to be more available than cattle manure. The Fulani tend to use the little cattle manure (Figure 5-2) available on their own farms.
2. A few expressed the intention of using manure, but observation around the farm area suggests that this rarely occurred in practice.
3. Animal manure shares some properties with ash. It has the benefits of being persistent in the soil but it releases its nutrients slowly. Frequently it is burnt to ash before application. One farmer said he did this to burn off all the 'germs' contained in the manure.

4. The farmers perceived differences in strength between various types of livestock manure and, in particular, they observed that poultry and egret manure were very strong and could 'burn' the crops.

5.1.2 SFM strategies in Rayfield with particular focus on the use of ash and poultry manure

The outcome of the survey carried out in four locations on the Plateau (4.7.1) showed that there appeared to be greater use of ash and poultry manure in Rayfield than around Delimi. This situation was investigated further with structured interviews in Rayfield (4.7.3). The interviews showed that, although the two locations share some common patterns, the situation in Rayfield is quite different from Delimi.

1. Most farmers think a combination of ash and IF is the best strategy because they are complementary and cover different roles. Neither used alone will give optimum yield. Some think that, used alone, ash will simply not be effective, the soil needs IF, too. When they open up new land, they combine ash, manure and IF and let it 'sink' into the soil for a while before planting. Thus treated, the land will yield results, as if it was land that had been under cultivation for many years. Other farmers would prefer IF (because it results in fast growth), if they could get enough but this is often not the case, so they mix it with organic materials because these are more readily available. The soil type will also affect the decision to use IF or organic materials or both, as certain fertilisers will be more effective on certain soils. One farmer gave the example of some soils strictly requiring super-phosphate (as well as NPK) before they could give a good yield, and other soils providing an adequate yield only with NPK.
2. Some farmers had noticed a decline in the strength of IF compared to the previous years. For this reason they had to combine it with ash or manure. One farmer specifically complained that some NPK produced in Kaduna had resulted in failure of his crops and that it was better to combine urea with super-phosphate.
3. Farmers use a lot of ash and also tend to mix it with poultry manure. The complaint that ash was not readily available was a common one: some thought it was because of increasing demand, others thought that ash was always available but it was difficult to obtain transport vehicles. Yet, other farmers complained that they had had to reduce the quantities of both ash and poultry manure because of expense and large transportation distances.
4. There are three sources of ash: domestic refuse from rubbish heaps around town; wood ash from cooking fires from large commercial places; farm waste, such as maize stalks.
5. Ash is free if the farmer goes to collect it in person from public sites, such as the JMDB dumping ground. He will need to prepare it himself (by burning and sorting *in situ*) but then

he only has to pay transport, the cost of which will depend on the distance he has to cover. If the farmer purchases the ash from someone who collects, burns and sorts refuse, it will cost him between 1000-1200 Naira for a pick-up truck, on top of transport costs. Sometimes tipper trucks are used, but pick-ups are more common.

6. Poultry dung costs about 1500 Naira per pick-up truck, on top of transport costs. Cow dung costs 3000 Naira per tipper load but it is used rarely because it introduces weeds to the farm.
7. JMDB does not service the Rayfield area for two reasons. Some areas are designated as urban development areas so the trucks cannot dump the refuse there, even if private vehicles can. Other remoter Rayfield areas are simply off route and JMDB truck drivers will not transport the refuse there. This was not always the case, as in the past, when JMDB had more vehicles they would go to Rayfield too.
8. A common reason for using ash is that it makes the crop 'expand'. A crop like tomato produces more branches, hence more space for flowering and, consequently, gives a better yield. Other leafy crops 'expand', produce more leaves and become greener. One farmer commented that it serves as a fertiliser: although at application it looks 'dusty', within three weeks the crops will have absorbed the dust and will grow vigorously. Ash can also be used to make the soil soft (one farmer commented that ash acts like farmyard manure), to help seeds germinate, and as a pesticide. Mixed with manure it becomes a very good fertiliser. If it is combined with IF it reduces the amount of IF that needs to be applied.
9. If used in excess, ash will dry out the leaves, particularly if there is 'dew'. It will stick to the leaves and can make them wilt. Ash will also be dangerous if it contains certain materials. One farmer had obtained ash which had contained burnt tyres, and he found that it acted on the crops as if it was 'acid'.
10. Poultry dung maintains soil structure and persists in the soil for a long time.

5.1.3 Quantification of agro-chemical and organic inputs used in Delimi and Rayfield

The survey (see 4.7.1) gathered, *inter alia*, information on fertiliser and pesticide use in Delimi and Rayfield. The data provide a general indication of the type and amounts of IF used but should be considered a guideline rather than an accurate inventory, as farmers often purchase inputs in small quantities and do not keep records. Furthermore, the farmer could express the intention of purchasing a particular IF but this would be conditional on its availability. Although each site should have been covered by 50 questionnaires, problems with the data in individual questionnaires meant that fewer farms could be included in the analysis.

To calculate an overall and individual rate of IF application for the whole season it is necessary to estimate the size of the farms. This was done according to the procedure outlined in 4.7.1, which gives a total farming area for Delimi of 11.7ha. Using the minimum and maximum subplot area values, a minimum-maximum area range of 8.75-15.99ha for the 48 farms is produced. The total farming area is likely to be underestimated when the average figure of 11.7ha is used because clearance of land occurs continuously throughout the season, and at the time of the survey (December) the majority of, but not all, land had been cleared.

The total farmed area occupied by 49 farms in Rayfield was calculated as 86.8ha. Individual farm areas were either based on the farmer's estimate (22 farms) or calculated by multiplying the total number of subplots per farm (27 farms—data not shown) by an average subplot area of 5.27m^2 (4.7.1).

Table 5-1 lists the total amount of each type of IF used in the two areas during the whole dry-season farming period. A general rate of IF application for Delimi can be calculated by using the total amount of IF employed over the whole season (irrespective of type) and the estimate of 11.7ha, and is 216g m^{-2} (or 2160kg ha^{-1}). This value is higher than the estimates for the farms in the trial in Table 6-10. An examination of individual IF application rates shows that Mu and Sa (who were coincidentally included in the survey) estimated their rates of IF application for the whole farming season at 76g m^{-2} and 160g m^{-2} respectively (this can be compared to the measured rates in Table 6-10 of 174g m^{-2} and 145g m^{-2} respectively). In the same fashion, the general rate of IF application for Rayfield was calculated as 100.9g m^{-2} (or 1008.6 kg ha^{-1}). It is interesting that the rate of IF application for Rayfield is approximately half the one for Delimi.

Table 5-1: Total amount of IF used (in 50kg bags) in Delimi (48 farmers on approx. 11.7ha) and Rayfield (49 farmers on approximately 86.6ha) over the whole dry-season farming period

Type of IF	*Delimi*	*Cost*	*Rayfield*	*Cost*
NPK (not specified)	143	1350-1900	343	1300-1800
NPK15:15:15	72	1300-2300	275	1300-1650
Golden NPK (NPK 15:15:15)	59	1500-2200	30	1500-1650
Compound or Kampa (NPK15:15:15)	46	1300-1700	271	1250-1800
Urea	139	900-1700	415	1300-1900
Golden Urea	2.5	1350-1500	-	-
Super-phosphate (supa)	44	1400-1700	298	1000-1900
Single super-phosphate (SSP)	-	-	16	1200-1300
TOTAL (bags)	505.5	-	1751	-

Cost range as quoted by the farmers = in Naira per 50kg bag. At the time of the survey £1 = Naira 180. NPK (not specified)= type not specified. NPK15:15:15= a brand consisting of grey, red and white granules. Golden NPK= white granules. Kampa = red granules.

It is informative to examine the individual rates of fertilisation for each of the two areas. Table 5-2 lists the number of farmers falling into each (arbitrarily defined) IF range. In Delimi

44% of farmers apply less than 100g m^{-2} of IF throughout the whole farming period, 35% apply between 100 and 400g m^{-2}, while the rest contribute to rates above 500g m^{-2}, with two anomalous cases of over 1000g m^{-2}. If the rates for each individual farmer in the survey are examined, the minimum estimated rate is equivalent to 25.5g m^{-2} (excluding two cases who did not apply any IF at all) and the maximum value is 1433g m^{-2}. In Rayfield, 45% of farmers have rates that are below 100g m^{-2}, 37% have rates between 100 and 400g m^{-2} and the rest have rates above this level, with two unusually high cases above 1500g/m^{2}. The minimum calculated estimate was 20g m^{-2} and the maximum 1943g m^{-2}. It is noteworthy that 86% of the farmers who gave their own estimate of farm size in hectares had rates that were below 100g m^{-2}, and in any case the remainder of these farmers did not go over 220g m^{-2}. By contrast, only 11% of farmers whose land was estimated by counting subplots had rates that were lower than 100g m^{-2}, and, in fact, 56% had rates between 100 and 400g m^{-2}, and the remainder were above.

Regardless of how accurate the estimated rates of fertilisation are, the tables are still very useful because they provide an indication of the type of IF used, the preference of the farmers for particular types, and an indication of cost per unit. If Delimi and Rayfield are contrasted in Table 5-1, by taking into account land area, it is apparent that consumption of super-phosphate is similar in both areas, but that Delimi farmers consume about 2.5 times more urea and NPK15:15:15 in respect to Rayfield.

Table 5-2: Number of farmers falling into each IF range category

IF range (g m^{-2})	*Delimi: Number of farmers (out of 48)*	*Rayfield: Number of farmers (out of 49)*
<100	21	22
100-150	6	8
150-200	2	3
200-300	5	5
300-400	4	2
400-500	0	0
500-600	3	1
600-1000	5	6
1000-1500	2	0
1500-2000	0	2

Organic fertilisers used in Delimi and Rayfield are shown in Table 5-3. It is immediately noticeable that Rayfield farmers rely heavily on organic amendments and purchase large quantities of ash and poultry manure (as denoted by the numbers of farmers purchasing in pick-up loads). The Delimi farmers often reported that they found it difficult to provide a figure for the amount of traditional fertiliser used throughout the season. Ash, in particular, was not always measured because they tended to make it from waste around the farm. Frequently they did not seem to know or measure the amounts of organic manure either: possibly it was because they used it occasionally and so could not give an exact figure, or maybe they owned domestic livestock and did not keep track of how much they used. By contrast, the Rayfield farmers were able to give more definite estimates probably because they organised the purchase and transport of organic amendments in large quantities.

Table 5-3: Total amount of traditional fertilisers used by 48 farmers (occupying an estimated 11.7ha) in Delimi and 49 farmers (occupying an estimated 86.8ha) in Rayfield over the whole dry-season farming period

Organic fertiliser	*Total (bags)*	*Cost/bag (Naira)*	*Total (pick-up loads)*	*Cost/pick-up load (Naira)*
Ash Delimi	27 (3) Not measured (30)	Free (farm waste)	-	(200/tipper load *)
Ash Rayfield	119 (6) Not measured (9)	80 Free	144 (28)	400-1500
Poultry Manure Delimi	79 (14) Not measured (8)	50-120	2 (2)	600-700
Poultry Manure Rayfield	363 (10)	80-200	176 (33)	800-2000
Cattle Manure Delimi	20 (4) Not measured (3)	40-100	2 (2)	300-600
Cattle Manure Rayfield	76 (3) Not measured (2)	50-160 Free	31 (9)	400-1600
Goat Manure Delimi	19 (5) Not measured (5)	50-200	1 (1)	700
Goat Manure Rayfield	6 (1)	60	-	-
Egret Manure Delimi	5 (1) Not measured (1)	60	-	-
Pig Manure Rayfield	-	-	2 (1)	700

The numbers in brackets that follow the total amount of a particular organic fertiliser indicate the number of farmers who contributed to that total estimate. Quite frequently farmers could not give an estimate of how much organic fertiliser they applied and this is indicated by 'not measured'. * None of the farmers in Delimi intended to order a tipper load of ash that year, but during the course of interviews they stated that it was possible to obtain a tipper load of refuse from JMDB for 200 Naira. At the time of the survey £1 = Naira 180.

5.2 THE RATIONALE BEHIND SFM PRACTICES

This section summarises the critical findings of SFM practices (5.2.1) and then moves into a discussion on knowledge (5.2.2): how farmers acquire knowledge, what the problems are in accessing knowledge, and how knowledge does not necessarily imply action. It concludes with an in-depth analysis of two connected findings: the reasons behind the apparent decline in the use of organic inputs and the over-use of IF (5.2.3 and 5.2.4).

5.2.1 Some critical findings about SFM practices

Sections 5.1.1 and 5.1.2 summarised the principles behind the maintenance of soil fertility in Delimi Langalanga and Rayfield. Six important points were drawn from them (there are additional interesting points about ash, but the discussion of these has been deferred to section 7.2).

The first point to make is that, as reported by Phillips-Howard and Kidd (1991), the farmers have a wide and complex *collective* body of knowledge about SFM practices. This issue will be discussed at greater length in 5.2.2.

The second is that the most common approach to SFM consisted of a combination of inorganic and organic fertilisers. Although farmers mostly relied on IF, it was the general consensus that the best results were obtained with a combination, and that every kind of fertiliser played a specific role within the SFM strategy. Many farmers stressed that the application of organic materials, particularly ash, reduced the crop's requirement for IF. It is striking that farmers who have no knowledge about the constituents of IF, already know about the benefits of the increasingly popular concept that is labelled in the 'scientific' world as integrated plant nutrition (Alexandratos, 1995)

The third is that there are almost as many soil fertility management strategies as there are farmers. It is remarkable that each farmer had a complex and different strategy that he believed was optimal for his land: it suggests that the farmers have learnt over the course of the years what produces the best results, through experimentation and careful observation. This is particularly striking when it is taken into consideration that for the most part, farmers are unaware of what each IF type contained as they had not been taught what these fertilisers consisted of (by extension agents who introduced them to the farming system). Each farmer has developed empirically, through trial and error, particular combinations and 'recipes'. Most were also aware that the type and amount of IF required would depend on the combination of crops grown and the soil type.

The fourth is that, as well as mixing inorganic and organic inputs, farmers have the tendency to mix different IFs at application. One farmer, for example, had a 'recipe' that consisted of a mixture of NPK15:15:15, urea and super-phosphate in the ratio of 2:1:1. This is not whimsical: it is probably learnt from the experience that for particular soils no single IF type is adequate. Indeed, as Alexander and Kidd (2000) and PADP (8.2.2.1) have observed, compound IF marketed on the Plateau is of the wrong formula for soils there. What was peculiar was the fact that some farmers seemed to make a distinction between different brands of NPK15:15:15 (what they called Golden, NPK 'fifteen-fifteen' (Plateau State brand) and Kampa), including one educated farmer, who knew that they were nominally identical IFs. This led to laboratory analysis of different fertiliser samples, which established that different brands of the same fertiliser were, in fact, not the same, either because the contents differed (in the case of K_20), or because the source varied, so would be differently soluble (for N). Results are presented in Appendix D. A related point is that a few farmers complained that IFs seemed to be getting 'weaker', and this could be a manufacturing problem (from Appendix D it is clear that in the case of NPK 17:5:5:17, the principal source of N differs from that of the other brands of NPK15:15:15 or 20:10:10) , or a first sign of declining soil fertility.

The fifth is that despite their acknowledgement of the importance of combining IF with organic inputs, this did not seem to be occurring in practice in Delimi. In Rayfield, farmers made wide use of ash and poultry manure, but in both locations there was the recurrent complaint that organic inputs were difficult to obtain. This problem is expanded upon in 5.2.3.

The sixth point is that, to some extent, fertilisation approaches are common to different areas but there can be some key differences. For example, farmers in both Delimi and Rayfield believed in combining inorganic and organic inputs, but Rayfield farmers did this to a much larger extent than Delimi farmers. Farmers in both areas applied ash, gave some common interpretations of what its effects were, but also some different explanations: in both locations ash softened the soil, it made the crops greener but only Rayfield farmers claimed that it made tomato expand, produce more branches and hence, more fruit.

5.2.2 How do farmers become knowledgeable and how can their knowledge be understood?

The process of acquisition of knowledge on fertilisation practices in Delimi is principally informal and empirical. Farmers have not learnt formally about plant nutrition or soil fertility issues. This was quite evident from the fact that, despite relying heavily on them and having developed sophisticated application strategies, farmers do not understand what the constituents of IF are.

Additionally, Harris and Dung (2001) have noted that farmers' knowledge of IF use efficiency on the Jos Plateau may be poor, and that they do not appear to understand the different values of the various IFs, nor the relative benefits of using single-element IF such as urea and SSP versus compound IF. They pointed out that during the survey (4.7.1) when farmers were asked which fertiliser they preferred, many answers centred around "*No* *preference, depends on availability*" while others answered "*I prefer…because it is strong, persistent, and makes the crops grow well*".

However, the in-depth interviews about fertiliser use and observation of fertilisation practices suggest that the situation is more complicated, at least in the Delimi farming area. The survey results suggest that farmers are not very knowledgeable about IFs, but the interviews show that the farmers have an understanding of what does work and what does not work. So, even if farmers *do not* know that urea only contains nitrogen (and crops require N, P and K), they *do* know that applying urea alone will, at length, result in crop failure, and that it is necessary to combine it with something else. During the interviews, the majority of farmers claimed to have a particular strategy that was ideal for their land or for particular crops, usually consisting of a combination of compound and single fertilisers. They varied the amounts and types depending on what they were growing. This indicates that the farmers have concluded, by empirical means, that compound fertilisers available on the Plateau are unsuitable for the soils there (as remarked on by Alexander and Kidd, 2000), and are combining IFs in an effort to meet crop demands.

There are three principal channels to access knowledge: learning from family, from other farmers or through experimentation. Many farmers will have commenced farming under the guidance of their fathers or other relatives, although some would have learnt farming as hired labour. Most farmers seemed to adopt the bulk of a particular 'style' they had been taught, with a few modifications. A few farmers would have started farming as adults, although almost all Nigerians (excluding the very affluent) will have had experience of farming at some point or other in their lives. On the Plateau, though, DSIVP was introduced by the Hausa migrants (3.5), and it is relatively recently that other ethnic groups have taken up this mode of farming. One non-Hausa farmer readily admitted that he had experience of rain-fed farming, but was new to DSIVP, so he was learning from his Hausa neighbours. Once farmers establish themselves independently, they may hone their skills by experimenting. So, ultimately, farming knowledge is far from being static. Farmers may have a broad approach, but they will make slight modifications, either because they observed a new successful strategy and decided to copy it, or they were informed about a new strategy without having seen it in practice, or they had an original idea that they wanted to test. The non-Hausa farmer, mentioned above, was particularly innovative and frequently tried out new ideas, despite being 'new' to the business. Perhaps the very fact that it was a new activity for him gave him the flexibility to test new ideas, whereas farmers who had farmed for many years were slightly more 'entrenched' in their routine.

The introduction of IF to the farming system is a good example of the evolution of farming strategies. Some of the older farmers remembered when IFs were introduced for the first time by agricultural extension agents. Initially, the farmers were suspicious of the new fertilisers and refused to use them. The agricultural extension agents ran trials on site, to prove that they could get a better yield. They also left sacks of IFs 'lying around' the farming area, in the hope that farmers would be curious to try it. When the farmers saw the outcome of the trial they were convinced to try the IFs themselves, and slowly IFs were incorporated into their practices. However, farmers did not passively exchange old fertilisers for the new, but they incorporated the new fertilisers into the old strategy, improving it. Phillips-Howard and Kidd (1991) conducted a study that showed how sophisticated the farmers' SFM strategy was, consisting of a combination of many different IFs, and types of manure and ash. This was done at a time when farmers had been exposed to IFs for many years and were used to them, but were finding it increasingly difficult to obtain them because of sharp decrease in government subsidised fertiliser.

Having described how farmers become knowledgeable about the management of soil fertility, there remain two questions. How can this knowledge be accessed and understood? And how does theoretical knowledge relate to practice? Concerning the former, there is a problem when it is necessary to decide *whose* knowledge counts. Some farmers may be more knowledgeable than others, and there may be different opinions. Whose knowledge is important, particularly when there is a disagreement? And what is the importance of individual knowledge versus collective knowledge? Where there is good agreement within a group of people it is clear that the piece of knowledge deserves reporting, but what about a comment coming from a single individual? There is the danger that if the comment appears sensible/intriguing/controversial to the recipient, it will be noted (regardless of its value), but if not, it may also be summarily and, incorrectly, dismissed. The positionality of the researcher will influence the selectivity of knowledge.

5.2.2.1 How is farmers' knowledge accessed?

Chapter 2 has reviewed the problems in accessing and understanding knowledge in a different cultural context. This section will address the issues that specifically affected the process of information gathering in this research.

In an attempt to be clear, the information obtained from the interviews with the farmers has been presented in this thesis as a continuous and fairly uniform body of knowledge (see 5.1.1 and 5.1.2). This, though, is quite obviously the re-elaboration of a more discontinuous reality because, in reality, knowledge was patchy and incomplete.

The most immediate problem, concerning access, was the language barrier. An interpreter had to translate the interview questions from English to Hausa and the farmers' statements from Hausa to English. Here two problems arise: is the interpreter translating correctly and how can untranslatable concepts be transmitted? The first issue was not too critical and the few problems encountered were resolved with time. It was unnecessary to record the interviews because most concepts being discussed were quite straightforward and not really open to misunderstanding. Farmers were questioned on which kind of fertiliser they applied, how much, how often, which they preferred, etc. At the beginning the interpreter was not translating everything that was being discussed because he thought that complaints about the government or about the state of health of the farmer, were unrelated to fertiliser use. With a little training he learnt to translate everything that was being discussed. Although it is possible that during the earlier interviews some information could have been lost because it was not translated, at a later stage I had mastered enough Hausa to follow the direction of the discussion, even if not the details, so that I was sure that all relevant issues were being translated. The second issue was more problematic. Some concepts that can be defined with a single word in English cannot be translated easily into Hausa. Here the interpreter would overcome the problem by giving examples. Sometimes the reverse would happen and the interpreter would use several words to provide a translation, to provide a flavour of what the word meant. This though did not happen frequently. What did happen more frequently was that a farmer would make an obscure statement that could not be translated. The literal translation did not mean anything in English, and the interpreter did not understand the concept himself, so could not even provide his own interpretation. Sometimes further questioning would help clarify the statement, but frequently with the older farmers nothing further could be obtained. Whether this misunderstanding derived from the fact that the interpreter was not a farmer and had received Western education to University level in a scientific discipline so could not relate to a farmer's way of thinking, or whether it was a problem of different ethnicity so that the interpreter did not fully relate to the cultural context (despite the fact that he had moved to the Plateau as a very small child, and was perhaps more fluent in Hausa than his native language), was unclear. A good example of this situation is the following dialogue between the interpreter and an old farmer, who was explaining the role of ash in the system:

> Interpreter: "*Why do you use ash? How does it work?*"
> Farmer: "*After you have eaten food, what do you do?*"
> I: "*I drink water?*"
> F: "*Correct. Fertiliser is to the crops like food is to you. Ash is to the crops like water is to you. After you eat food, you need water. After you give crops IF, they need ash*".

Despite further questions to clarify what he meant, the farmer could not explain the concept in 'western', 'scientific' terms. The categories he was using (fertiliser/food and ash/water) are not comparable in a 'western' framework, although they may be in his own cultural setting. This is a problem when *tacit* or *informal knowledge* (which is subtle, personal, involves beliefs, perspectives and values, and relates to the individual's experience and ability to perform certain tasks) needs to be transmitted as *explicit* or *formal knowledge* (which is articulated through language, and conveyed as information) (Morgan and Murdoch, 2000; de Sá Carvalho *et al.*, accessed at: http://in3.dem.ist.utl.pt/downloads/cur2000/papers/s17p06.pdf).

Access to knowledge is also difficult because it is spread out between people. Some knowledge was common to all but, on the whole, different farmers had different knowledge. Their knowledge was drawn in part from a common body of knowledge (that could be shared amongst peers or passed from parent to son) and, in part, from specific, localised experiences. Some farmers were more knowledgeable than others, or more willing to share their knowledge. Some farmers were better able than others to articulate their ideas in a format that was accessible and understandable to a 'Western' way of thinking. So, for example, all farmers seemed to share the idea that it was better to combine organic with inorganic fertilisers (point 5 in 5.1.1 and point 1 in 5.1.2), but only a few explained that the use of IF alone would 'harden' and 'ruin' the soil. The question remains of whether the latter farmers were more knowledgeable than the remainder, or whether the remainder knew that IF alone would degrade the soil but thought that this idea was implicit in the statement that the optimal strategy was to combine organic and inorganic inputs.

Knowledge is spread out *within* areas, but also *between* areas. It was interesting to compare knowledge across Delimi and Rayfield (see 3.5 for a profile of farmers in the two areas). Within each site there were common themes, which were sometimes, but not always, matched across sites. The idea of combining inorganic with organic fertilisers was recurrent across both areas, as was the opinion that ash acted by softening the soil and making the crops greener. However, in Delimi, farmers stressed that the softening of the soil allowed the root crops to spread out and expand in the soil, but in Rayfield when farmers referred to the crop expanding they were talking about the upper portion of the crop, the leaves of lettuce, or the branches of tomato. No farmer in Delimi stated that a crop produced more leaves or branches as a result of ash application. Farmers in Rayfield also mentioned the problem of ash drying out the crops by sticking to the leaves, particularly if there was dew. Farmers in Delimi did not express this idea. To some extent the way knowledge is expressed will depend on what farmers think is most relevant and this will depend on what their activities and priorities are. So, farmers in Rayfield were more forthcoming about information about poultry manure and ash, whereas farmers in Delimi tended to respond by discussing IF and had to be specifically questioned about organic materials. This was clearly because farmers in Rayfield used a lot of organic materials, whereas farmers in Delimi seemed to be phasing them out. This did not mean that farmers in Delimi had no knowledge about organic materials, they did, but if they were asked generally about fertilisers they discussed IF and perhaps ash, because they did not rely on manure any longer.

The challenge for the researcher is, thus, to package and process this information to pass it on to the outside world. Yet, how? It is acknowledged that the process of drawing together this diverse body of knowledge is highly subjective. Throughout this research, there has been an attempt to concentrate on well-established, common themes, but obviously in some situations, there has been a conscious decision to incorporate isolated comments because they were considered relevant or to exclude comments that appeared irrelevant (or in some cases, that could not be understood). This, unfortunately, is a problem that can be recognised but never completely solved.

5.2.2.2 Knowledge does not translate into action

A problem (that became apparent over the course of the farming period) with making generalisations about farming and fertility strategies is that knowledge does not necessarily translate into action. Farmers may provide ideal-type descriptions of what they do, when, in fact, their actual practices do not arise out of a rational 'plan' but out of a series of contingent responses to uncertain circumstances (Scoones and Thompson, 1994b). The interviewees in the study area often stated their intention of using several different inputs, in a determined order and combination. A few farmers cautioned that the use of a particular input would depend on its availability at the right time and, in reality, the vast majority of farmers did not follow the plan they had described in the interview. Examples of this have been incorporated in the discussion in section 6.3.3. Farmers were particularly 'unreliable' concerning the use of organic fertilisers, such as ash and manure. Most expressed the desire of using these inputs, if they could obtain them, but in practice, very few did. Therefore, despite the recurrent idea of the complementary roles of organic and inorganic fertilisers, farmers, in fact, chose to focus their resources on obtaining inorganic inputs only. This is peculiar, particularly when it is considered that there are testimonies of large quantities of organic materials being used in this area in the past (Phillips-Howard and Kidd, 1991; Alexander, Pers. Comm.) and that farmers in Rayfield used substantial quantities of poultry manure and ash.

The lesson from this is that it is not sufficient to ask a farmer what he does or what is best, because he may say what he would like to do, or what he has always done, and omit to explain that he will not be doing it because the circumstances have changed. This is not a deception on the part of the farmer, because he may simply be explaining what *should* be done, rather than what *can* be done. This means that interviews and surveys should be followed up, if possible, with close monitoring and observation of activities.

5.2.3 The decline in the use of organic inputs

As mentioned in 5.2.2.2, farmers in Delimi claimed to use organic inputs alongside IF but, in practice, they concentrated all their resources on acquiring IF. This raises the question of what might have determined this apparent decline in the use of organic materials. Sections 5.1.1.1 and 5.1.1.2 list a number of constraints connected to the use of urban waste ash and manure. The farmers complained particularly of the rising cost of these materials, the labour involved in preparing the ash and the scarcity of manure. Before advancing any opinions on this issue, emphasis must be placed on the noticeable contrast with Rayfield. The interviews in Rayfield almost invariably revealed that farmers used IFs but combined them with substantial quantities of ash and poultry manure. They purchased these materials using several private tipper-truck or pick-up van loads, and could provide information on the cost of the actual material and transportation, and where it could be obtained. They gave the impression of actively seeking and purchasing these organic inputs, unlike the Delimi farmers who explained that they would purchase organic materials if they had sufficient money to do so. The Rayfield farmers also complained of rising cost (and in some cases, scarcity) of these materials, and explained that they had been forced to reduce the quantities they bought.

Thus, a common feature of the two sites is that they are experiencing increasing difficulty in obtaining organic inputs, because of rising cost and scarcity. The scarcity could be related to the expansion in DSIVP in the last decade, which is putting pressure on limited resources. The difference is that in response to these mounting difficulties, Delimi farmers seem to have phased out organic inputs almost completely (except for farm-produced ash), while Rayfield farmers have simply reduced the amounts they use. Two questions need to be answered and, at the moment, only speculative answers can be suggested. The first question is why has the decline in organic inputs been more noticeable in Delimi than in Rayfield? One possibility is that because of their location, Delimi farmers were used to obtaining cheap or free organic inputs. The farming area is adjacent to the University Staff Quarters, and several farmers commented that before keeping poultry became a business they used to be given the manure for free by the residents of the quarters. Similarly, they were used to easily obtaining a truckload of town refuse ash from JMDB. In recent years, they had been experiencing difficulties and the price had increased so much that only the richer farmers could afford to buy a truckload. Something that the farmers did not comment on, but was gleaned from the interview with a representative of JMDB, is that JMDB currently operates with four tipper trucks (from the original twenty-three that were commissioned to service Jos). It is obvious that with only four trucks for the whole town, fewer farmers will be able to make arrangements for a load of refuse. The fact that the Delimi farmers were used to easily obtaining cheap or free organic inputs might mean that they are reluctant to start purchasing them at high cost. In contrast, the Rayfield farmers work in a remote site, so it is probable that they are used to making private arrangements with pick-up trucks for a load of ash or poultry manure. Furthermore, they are more conveniently located in respect to an intensive poultry-rearing unit, the ECWA–POD project, which is located along the Rayfield-Bukuru Road. Their response to increased cost would consist of a reduction of the quantities used, rather than complete elimination.

A second possibility is that the reduction in the use of urban waste ash in Delimi is linked to the availability of IF. One farmer explained that the use of town refuse ash fluctuated from year to year: when IF was freely available it was in low demand, but when IF was scarce ash was highly sought after. This explanation is not incompatible with the situation in Rayfield: it is clear that Rayfield farmers have a different strategy than the Delimi farmers, as they rely heavily on poultry manure. As they traditionally mix poultry manure with ash, it is obvious that while they continue to purchase poultry manure they will continue to procure ash, regardless of whether IFs are freely available or scarce.

A third explanation is connected to the soil characteristics in the two areas. Irrigated farming began approximately 60 years ago in the Delimi Langalanga area: initially, it was restricted to areas close to the Delimi river which could be irrigated by hand methods, and only in the last 20-25 years did it expand to un-modified mine lands because of the introduction of the pump engine (Alexander, 1992). Most of the Rayfield area consists of abandoned mine land (Dabi, 1992), and the greater part would have been brought under cultivation in the last 20-25 years, with the introduction of the pump engine. It is possible that the Rayfield soil is poorer than most of the Delimi Langalanga area because it has been under cultivation for a shorter period and, therefore, the integration of IF, poultry manure and ash is an essential practice.

The second question is why has the price of organic inputs increased? Here two factors could be important. Firstly, it has been noted that dry season irrigated farming has expanded dramatically in the last ten years, leading to the opening up of completely new areas (Adepetu, Pers. Comm.). The expansion of the farming area could be connected to the scarcity of poultry manure and the increased demand for this input would drive prices up. Similarly, all other types of manure are likely to be costly because they are in high demand. The complaint that cattle manure was less available than poultry manure was linked by the farmers to the fact that the Fulani owners tended to use the manure on their own farms rather than sell it. This is an interesting development as traditionally the Fulani people herd cattle but do not farm. However, for various reasons (land tenure, changes in grazing access, schooling, etc.) some Fulani have sedentarised: i.e. they have a home base and although they may go on migratory trips, many do not go far. The homestead enables them to take up agriculture, so although they are primarily livestock keepers, many do farming as a secondary activity. As a consequence, when the Fulani start farming, they will use the manure themselves, rather than give it to others. Even those Fulani who claimed to farm full-time in the survey (4.7.1), frequently had access to cattle manure through their relatives.

Secondly, the expense of obtaining organic materials could be strongly influenced by the cost of petrol. Farmers complained frequently of the scarcity and consequent high cost of petrol for running their pump engines. It follows that the cost of hiring a pick-up truck will be prohibitive, (particularly for Rayfield farms that are distant from built-up areas, that are the sources of organic materials), and farmers may choose to reduce the number of loads they purchase, or rely completely on IFs which can be transported by hand in small quantities or, perhaps, on a motorbike.

5.2.4 The over-use of IF

Section 5.1.3 provided information pertaining to the use of IF in Jos. The application of large and, probably, excessive amounts of IF seems to be a common pattern across Delimi and Rayfield. It was estimated that in the course of one dry season, farmers applied an average 2160kg ha^{-1} and 1009kg ha^{-1} of IF (irrespective of type) in Delimi and in Rayfield, respectively. Although it would appear that Delimi farmers apply double the amount of Rayfield farmers, Table 5-2 indicates that this is probably caused by a few more outliers in Delimi as, in reality, in both areas at least half of the farmers applied less than 1500kg ha^{-1}. Most IF consists of approximately 50% of active plant nutrient so on this basis most farmers apply between 500 and 1000kg ha^{-1} of plant nutrients. This figure is far from being in the range calculated by FAO for Sub-Saharan Africa, where the 1988/1990 application rate was put at 11kg ha^{-1} (in nutrient content) and was projected to rise no more than 21kg ha^{-1} by 2001. The figure is still higher than the largest IF consuming areas in the developing world (in 1988/1990 it was the Near East/North Africa) with 89kg ha^{-1} (Alexandratos, 1995). However, FAO's estimates refer to subsistence agriculture rather than commercial cropping. The consumption patterns of the Delimi and Rayfield farmers are equivalent to those of a developed country, for example, in the U.K., a demanding crop, such as potatoes, typically requires 198kg ha^{-1} of N, 209kg ha^{-1} of P_2O_5 and 278kg ha^{-1} K_2O (i.e. a total of 785 kg ha^{-1} of plant nutrients) (Burrell *et al.*, 1990). Furthermore, the estimates for IF consumption in Jos described so far have not taken into account the provision of nutrients by organic fertilisers, such as ash and manure, which are used in considerable quantities, particularly in Rayfield (Table 5-3).

Despite the fact that farmers would appear to overuse IF, a caution must be made that there may be good reasons for this. Other authors working in Nigeria (Hoffman *et al.*, 2001), have remarked on the fact that IFs available in Nigeria are not what they are marketed to be (i.e. they do not contain the amounts that they are advertised to contain). Laboratory analysis of fertiliser samples confirmed that the manufacturing companies were not always producing fertilisers with the advertised contents, and they were using different sources of nutrients, which would also affect solubility (Appendix D). For example, if NPK15:15:15 (Golden brand) is contrasted to NPK27:13:13 (same brand), it is clear that the 15:15:15 contains the correct *total* quantities of N, but only 5% can be measured as NO_3. It also contains the correct amount of K_2O, but has double the amount of P_2O_5. The NPK 27:13:13 once again approximately contains the correct *total* amount of N, but this time only 0.81% can be measured as NO_3. It contains a larger amount of P_2O_5 (20%) than advertised, but much less K_20 (9.1%). In addition to the unreliable manufacturing, as Alexander and Kidd (2000) and PADP (8.2.2.1) have observed, many of the compound IFs that can be purchased by the farmers, are frequently of the wrong formula for the Plateau soils. So, if it appears that inorganic IFs are being overused, it may be as a result of the necessity to apply sufficient amounts of one particular nutrient (for example N), even if it ends in the over-application of another nutrient (for example K). Furthermore, farmers are constantly faced with logistical constraints: their preferences may not be viable if, at the time of purchase, the particular IF they desire is not in stock, or it is too expensive. In fact, several farmers complained of the scarcity of particular IFs they found useful, such as di-ammonium phosphate (DAP) and NPK27:13:13.

In conclusion, in the light of the IF data collected in 5.1.3, coupled with interview information which indicates that organic manure is scarce, it would appear that farmers are applying excessive amounts of IF. There may be problems with the quality of the IF, but it is likely that the major reason for over-application is that the compound fertiliser is of the wrong formula for the Plateau soils.

5.3 HOW DO CURRENT SFM STRATEGIES COMPARE TO THE PAST?

The introduction to this chapter explained that the applicability of Phillips-Howard and Lyon's (1994) conclusion to the current situation would depend on how socio-economic conditions have changed. This *per se* is difficult to measure: it is simpler to determine what the current SFM strategies are in relation to the past, on the assumption that if farmers were continuing with approximately the same SFM strategy, they would be maintaining soil fertility levels (this information could then be correlated to the outcome of the soil fertility tests in the case study farms in Chapter 6).

The basic soil fertility maintenance strategy has not changed since the work in the 1990s. Phillips-Howard and Lyon (1994) reported that the traditional strategy consisted of a mixture of sawdust, ash and cow manure. With the arrival of IFs, farmers incorporated these into their strategy and started using complex combinations of IF, ash (various types) and manure (various types). Over ten different combinations were identified, such as refuse ash and sheep or goat manure, super-phosphate and calcium ammonium nitrate (CAN), super-phosphate and urea, urea and manure or ash (Phillips-Howard and Kidd, 1991; Phillips-Howard, 1994). Farmers' knowledge in mixing fertilisers covered the characteristics and usefulness of various types; the compatibility of different fertilisers; fertiliser equivalence and inter-changeability, in terms of their strength (*karfi*) or whether they were hot (*zafi*) or cold (*sanyi*); suitability for different types of land; ways of mixing to achieve 'good' crops, high yields and reduction in costs of fertilisers (Phillips-Howard and Lyon, 1994). It was stressed that farmers combined fertilisers not to balance nutrient supply with crop requirements but to gain satisfactory yields with limited fertiliser input. Currently, farmers still subscribe to the principle of combining different fertilisers, but in practice there have been changes.

Farmers in peri-urban Jos are heavily reliant on IF. Even though they may advocate combining inorganic with organic materials, in practice in Delimi this happens rarely (the major exceptions are farmers who make their own ash and the few Fulani farmers who have access to cow manure) and, in Rayfield, the complaint that organic amendments were scarce and expensive was widespread, even though they were used (see 5.2.3). Therefore, within a decade the situation seems to have been reversed. Both in 1991 and in 2000 there were complaints of fertiliser shortages. In the 1990s, however, the farmers complained about the scarcity of IF, and as a result, they optimised the use of the little IF they had access to, and attempted to reduce expenses on IF by turning to the more readily available organic amendments. Cattle manure, though unpopular because it apparently had seeds that caused weed infestation, was readily available (Phillips-Howard and Lyon, 1994). In 2000, farmers continued to complain about fertiliser, but this time the complaint was not related to availability, but to cost of IF. With sufficient money, IF was easily available, although certain types seemed to have disappeared from the market. The 2000 survey (Table 5-1) showed that farmers purchased NPK15:15:15, urea, triple super-phosphate, single super-phosphate and other forms of compound NPK (unspecified, but probably NPKMg17:5:5:17 and NPK27:13:13, which were sold at PADP's headquarters), whereas in the 1990s they additionally used CAN and di-ammonium phosphate (DAP) (Phillips-Howard and Lyon, 1994). A few farmers complained particularly of the disappearance of DAP, which they had previously found very useful. Unlike 1991, though, in 2000, organic inputs were both expensive and in short supply, so that farmers in Delimi had almost ceased acquiring them, and Rayfield farmers had severely reduced the quantities they purchased. So, farmers who stated that it was important to combine different types of fertiliser because each had its own role, were actually privileging IF over organic amendments, despite the high cost of IF (section 5.2.3 has already considered potential reasons for this).

The research carried out in 2000 came to similar conclusions as the detailed study by Phillips-Howard and Kidd (1991) on knowledge and management of soil fertility, but it extended this work by investigating the characteristics and supply of urban waste ash (as recommended by the authors themselves, in the conclusions). These findings are presented in Chapter 7. Although the two studies agreed closely on many issues, to conclude it is perhaps worth drawing attention to the discrepancies. Some contrasts are inevitable because different people were doing the interviewing and different people were being interviewed. For example, in 1991, the farmers reported that town refuse ash would rot the leaves of the crops if it settled for a long time, but in 2000 this idea was never expressed. However, this idea was mentioned in Rayfield. This is a small problem, but there are larger issues that are important. In 1991, farmers had specific preferences for certain manure types, and they were very thorough in explaining the benefits and disadvantages of each type. Cow manure was readily available, but it was disliked because it brought weeds to the farm. Town refuse ash was considered very useful and cheap. In 2000, it was very difficult to elicit information about organic fertilisers. If asked about fertilisers, farmers would start by describing which IFs they would use, and in what combinations. Some would add that they would use ash, but mostly farmers had to be prompted to talk about organic amendments. In this case, they would state that they would use ash if they could obtain some, if they had extra money, and almost all said that, although they would like to use it, animal manure was expensive and scarce. Only poultry manure was comparatively available, cattle manure was almost impossible to buy.

5.4 FUTURE TRENDS

The findings discussed in 5.3 are quite worrying. In the 1990s, there was still a lot of *fadama* land and irrigable mine land available for cultivation and it was predicted that: "*As more of this is cultivated, its fertility is likely to be raised through the resourcefulness and ingenuity of dry-season farmers encouraged by the profitability of vegetable production.*" (Phillips-Howard and Lyon, 1994, p.263). This prediction may have been borne out to some extent, as farmers have continued to expand DSIVP and are obtaining good crops, but the question today is, have the limits of the system and of the farmers' ingenuity been reached? The farmers are constantly complaining about the high cost of fertilisers, and there is a definite indication that the supply of organic manure has been exhausted. There is simply not enough for all the farmers involved in DSIVP. Are farmers complaining about the lack of IF because they have not accepted the loss of government-subsidised fertiliser, or is this cry symptomatic of declining soil fertility? There is some evidence for this (albeit coming from a very few farmers) in the comment that IFs seem to be less strong than they used to be. Farmers could respond by using town refuse ash or producing compost, but this does not seem to be happening. Here, too, farmers complain that refuse ash is either too expensive (Delimi farmers) or scarce (Rayfield farmers). The latter comment is strange, given the large amount of waste that is visible by the sides of the road in Jos. However, at the time of the research, there was a severe petrol shortage in Jos and this was a strong limiting factor in acquiring pick-up loads of organic manure or refuse ash. Thus, when Rayfield farmers stated that refuse ash was scarce, they probably meant that within the radius that they could afford to travel in, refuse ash was rapidly exhausted.

The possibility of producing compost is limited, as in the case of refuse ash, by the scarcity of urban waste, but also by the fact that it is a labour-intensive process. Farmers were questioned about compost production. It turned out that it is a technology they are familiar with, but do not practise, because of the labour involved. When it is considered that farmers work from the early hours of the morning, through to 4 or 5pm every day (i.e. using most of the hours of daylight), pausing only for an hour for lunch and prayers, it is perhaps unsurprising that they prefer the simpler task of burning and sorting the refuse, rather than composting it. As agriculture in this area is not mechanised (the sequence of farming activities has been described in section 3.6), it is clear that farmers need to rely on family or hired help. Farmers in Delimi managed their farms with a median of 4.5 labourers. The number of labourers ranged from zero to 15 depending on the size of the farm, and the socio-economic status of the farmer. In Rayfield labourers ranged from zero to 22, with a median of 5 per farm. In Delimi, those farmers who had labourers could rely exclusively on family members (25%), or on hired labour (35%), or use a combination (40%). In Rayfield the majority employed a combination of family and hired help (61%), 35% relied exclusively on hired help, but only 4% relied exclusively on family labour (all data derived from survey described in 4.7.1). Generally, there did not seem to be a particular partitioning of duties amongst the various workers (although it is admitted that this issue was not investigated in any great detail, and these comments are the fruit of casual observation). Owners, family members or hired labour would all take part in the same tasks, with the owner frequently weeding or clearing land alongside his labourers. The exceptions were provided by those owners who were too weak and old to work (the management of the farm would be entrusted to a son or close family member), or those large-scale farmers, who were also successful businessmen, who would frequently leave tending of the farm to junior family members and hired help. Therefore, neither owners nor labourers could spend much time preparing and tending a compost heap. It is conceivable that female members of the family could be involved in compost making, but a caution must be made that in neither of the two locations were women seen to be taking part in farming activities. As these are predominantly Muslim communities it is probable that married women are kept in seclusion.

This whole discussion leads to a number of predictions for the near future:

1. Organic manure is likely to continue being scarce, and the situation will worsen, if DSIVP continues to expand.
2. Town refuse ash could be an alternative, providing the government resolves the problem of the lack of vehicles for Municipal waste collection and of petrol shortages. It appears that

recently the situation has improved because of government intervention (Brown-Peterside, Pers. Comm., November 2001). Compost could also be an alternative, if the problem of labour can be addressed. Farmers are financially constrained regarding the number of labourers they can employ. It may turn out to be more cost-effective to encourage large-scale production of compost to sell to the farmers, rather than get farmers to produce it individually.

3. Even if suitable compound fertilisers for the Plateau are developed, if farmers cease using ash, and rely exclusively on IF, soils could rapidly acidify and degrade.

5.5 SUMMARY

This chapter has described the current SFM practices, both in terms of characteristics and quantities of inputs applied. It has emphasised the critical features of these practices, acknowledging the fact that gaining access to knowledge and information is not straightforward. In particular, it has discussed the apparent decline in the use of organic inputs and increase in IF use. It has also examined current SFM practices in relation to the past practices in the same area (as reported by Phillips-Howard and Kidd, 1991 and Phillips-Howard and Lyon, 1994), and has made some predictions for the near future.

The next chapter will look more closely at the effects of SFM strategies on the soil, through the use of case studies, whereas Chapter 7 will examine the nutrient and heavy metal characteristics of town refuse ash and examine the possible role that ash plays in the system. Both chapters will draw on information presented in this chapter.

6 THE SUSTAINABILITY OF THE FARMING SYSTEM

This chapter addresses the second aim of the thesis to provide an insight into the sustainability (in terms of nutrient supply) of the local agricultural system. The approach to this was to use case study farms. Care must be taken in the extrapolation of these results to the whole farming system, but they can be combined with information on SFM practices across the study area, to provide an indication of what might be happening in the wider area.

A first step towards ascertaining whether cultivation practices in the study area are sustainable involves the examination of the soil characteristics of each of the study farms. Each farm has to be considered an independent case study, because the thesis was based on monitoring rather than rigorous trials. This means that not only is each farm fertilised differently, each farm can be characterised by different crop combinations and management practices. Even if the results cannot be conclusively extended to the whole study area, the four case study farms (and the additional data for Ab and Mu) provide a realistic representation of what might be happening across the farming area. Farming systems like the one under study are always difficult to judge because diversity and change between and within farms are such important components, and because the financial situation of each farmer affects his ability or otherwise, to purchase all or only some of the inputs that he requires.

It is useful to briefly recap how this aim was to be achieved. The research followed six farms in the study area, which are designated as Audu (Au), Hassan (Ha), Salem (Sa), Shitu (Sh), Abdullahi (Ab) and Musa (Mu). Four objectives (II to V) were particularly relevant to this part of the research. The first objective consisted in collecting data on general soil nutrient and heavy metal properties, to determine any potential deficiencies or toxicities. This exercise was carried out in full for the first four farms in the list, and in part for the remaining two farms (see 4.4.2), and the results will be presented and discussed in section 6.1. The second objective took a long perspective, as it examined the differences between cultivated and uncultivated sites on each farm, to determine the long-term effects of farming practices on the soil. As with the first objective, this was done in full for the first four farms, and partly for the other two. The third objective attempted to establish whether farmers were meeting crop nutrient demands, by examining the changes in nutrient levels over the course of one farming season. This has been done for the first four farms. The outcome of these two objectives has been presented and discussed in section 6.2. Section 6.3 completes the discussion in 6.2, as it correlates the soil data to the specific farming practices. The fourth objective examines the potential for heavy metal accumulation in the soil and in the food chain. The first part of this objective is addressed in section 6.1 and the second part in 6.4, and in addition, section 6.4.4 examines whether irrigation water is a source of heavy metals. Section 6.5 draws together all the information from the case studies, and widens the debate, by comparing it to research carried out in the past in this area, and by examining current SFM strategies across the study area.

6.1 NUTRIENT AND HEAVY METAL STATUS OF THE SIX CASE STUDY FARMS

The six case study farms were located along the Delimi River on the upper terraces (Figure 6-1), above the flood plain. Typically, the farmed soil in this area is a silty or sandy loam, slightly acidic (an average pH 6.5), characterised by very low organic C (0.87g $100g^{-1}$), low total N (0.09g $100g^{-1}$), medium–high available P (7.11mg $100g^{-1}$), low cation exchange capacity (7.0$cmol_{(c)}$ kg^{-1}), probably because of the high proportion of kaolinite clay (Hill and Rackham, 1973), but high base saturation because of the large quantities of exchangeable Ca, K, and Mg (10.28, 0.57, 1.56$cmol_{(c)}$ kg^{-1}, respectively). Salinity is not a problem in this location.

Figure 6-1: Terracing in the Delimi farming area

The following section presents the key data necessary to characterise the cultivated and uncultivated sites for each case study farm, and this is followed by a discussion on the nutrient and heavy metal status and whether there are possible deficiencies or toxicities of any one variable (objective II). This analysis is based on mean values, without any consideration of the statistical differences between farms.

6.1.1 The data

In the first instance it is necessary to give a brief description of each farm and owner. Au and Ha were neighbours. Au was a large-scale farmer, also a successful trader, who cultivated several different sites (some he owned, some he rented). He appeared to be in his early forties and was married (probably with children but this was not ascertained). He tended to leave the management of the farm in the hands of a brother, so he could devote himself to his commercial activities. He could afford to hire at least seven or eight labourers to tend his farm. He farmed during the wet season on portions of land that were not flooded by the river. The portion of land under study (which he rented) was, in fact, located some distance away from his major farm. Ha was a small-scale farmer, under 30 years of age and single. He worked closely with a younger, unmarried brother, and he had inherited the farm from his father. He did not employ any labourers, and he always sold the produce to two other relatives who were traders. He did not farm during the wet season. Both Au and Ha's farms consisted of two or three terrances, and the study plots were placed on the upper terrace and were adjacent (divided only by a row of banana trees). The soil appeared texturally similar and, indeed, both farmers believed it was the same soil type. The management of the farms, however, was different (6.3.3): Au had a tendency to apply a single type of IF (some form of NPK15:15:15), whilst Ha usually mixed NPK15:15:15 with urea. Both farmers applied ash and claimed that in the past they had used large quantities of town refuse ash. In this particular farming season, Au applied farm waste ash, whereas Ha applied town refuse ash.

Sa and Sh's plots were next to each other, above the flood plain, but in Sa's case this was not the highest land he had brought under cultivation. Sa was a large-scale, successful farmer. He was young, between 25 and 30, and married with one child. The farm was in fact owned by his father, who was too old to tend it. The father was, however, a successful businessman and they often used revenue from the commercial activities to tend the farm. Management of the farm was left entirely in Sa's hands, although as the father still retained ownership, it is probable that a large part of the income was controlled by him. Sa hired at least six labourers, and during the wet season farmed on the upper portions of the farm (not on the plot under study). Sh was a small-scale farmer. He was 48, married with one wife and seven children, none of whom worked on the farm. He hired his land, when he could afford to he employed one labourer part-time and did not farm in the wet season. The soils had a similar texture and both farmers recognised that the study plots were the same soil type. Additionally, Sh believed that Au and Ha's farms, which were separated from his by a small watercourse, were the same soil type. Sa and Sh's management strategies differed quite strikingly: Sa applied a combination of NPK15:15:15, urea and super-phosphate, and never applied ash because he thought the soil was sufficiently 'soft' and did not require it. He did, however, apply ash to other sections of his farm. Sh only applied NPK15:15:15 but combined this with large quantities of farm ash, which he thought was essential.

Ab and Mu's farms were located on the opposite east bank of the river. Ab was a large-scale, full-time farmer, who held an important position in the farming community. He had a lot of experience (he would have been in his late 60s, early 70s), but his senior position made it difficult to obtain precise information about his background. Two of his children occasionally worked on the farm (when the eldest was not at work, and the youngest was not at school) and additionally he employed about five or six labourers. He rented his land, however, despite his prominent position and large amount of land, he did not appear to be as successful as Au and Sa, possibly because he had no trading connections. Certainly, he could not afford to purchase a new pump engine (he borrowed from a neighbour), and his produce was often bought by Au, who then re-sold it in the South. He did not farm in the wet season. Mu farmed as a secondary activity. He was 35, married with three children, but his wife had health problems. His permanent residence was outside Plateau State, so during the wet season he went back home. He hired an extremely small plot of land, he had a problem with access to irrigation water (his farm was on very high ground), he clearly did not use labourers, but because of his main trading activity (not market gardening products) he seemed well-connected with other traders. Both farmers thought their land was similar, even though they were not neighbours. Mu was located on higher ground than Ab, although both were above the flood plain. Ab predominantly applied a combination of NPK15:15:15 and large quantities of refuse ash, whilst Mu combined NPK15:15:15, with urea and super-phosphate, and applied a small amount of town refuse ash.

To some extent, the opinion of the farmers has been confirmed by examining the colour and texture of the top 30cm of soil (as this is the typical rooting depth of vegetables—Landon, 1984). Au and Ha are silt loams, whereas Sa and Sh are sandy loams. Ab and Mu are texturally dissimilar, as Ab is a sandy loam (like Sa and Sh) and Mu is a loamy sand (Table 6-1).

Table 6-1: Characteristics of cultivated and control soils in terms of texture and colour

	Texture (USDA classification system)	*Colour (Munsell)of re-wetted soil*
Au	**Silt Loam**/Loam	10YR 3/4 & 3/6-dark yellowish brown
Au c	**Silt Loam**/Sandy Loam	10YR 3/4-dark yellowish brown
Ha	**Silt loam**	10YR 3/6-dark yellowish brown; 2.5Y 5/6-light olive brown
Ha c	**Silt loam**/Sandy loam	10YR 3/3-dark brown
Sa	**Sandy loam**	10YR 3/6-dark yellowish brown
Sa c	**Sandy loam**	10YR 3/3-dark brown; 2/2-very dark brown
Sh	**Sandy loam**/Loamy sand	10YR 3/4; 3/6-dark yellowish brown
Sh c	**Sandy loam**	10YR 2/2-very dark brown
Ab	**Sandy loam**	10YR 3/4-dark yellowish brown; 7.5YR 4/6-strong brown
Ab c	**Sandy loam**/Loam	7.5YR 4/4-brown/dark brown; 10YR 3/4-dark yellowish brown
Mu	**Loamy sand**	10YR 3/6 & 4/6-dark yellowish brown
Mu c	**Loamy sand**/Sandy loam	10YR 3/6 & 4/6-dark yellowish brown

A very effective way of viewing the results for every variable and obtaining an initial impression of differences is to view the relative position of the means and the width of the 95% confidence intervals (CI). Minitab's graphical summary is a simple yet informative visual tool, as it provides a general impression of the data and may help identify subtle trends. The 95% CIs portrayed in the figures below are incorrect because they are derived from the pooled standard deviation. This is because Minitab's output was obtained by applying simple one-way analysis of variance to all control soils and all cultivated soils (this procedure is statistically incorrect but was used to obtain Minitab's graphical summary). The figures below (Figure 6-2 to Figure 6-17) provide information on the mean, the standard deviation and the 95% CI for each cultivated and each control soil of the study farms. The control soils were represented by ten samples taken approximately at T2, while the cultivated samples were represented by ten samples taken at T2 or T3 (for details see 4.5.2). It is re-iterated that the figures should be inspected for general trends only, not for statistical differences. The caption for Figure 6-2 can be applied to all successive figures.

It is essential to note that all figures and tables in this section, and *all of the following sections*, are supported by two tables of means, presented in Appendix E. Table E1 contains the means for all variables, for control and cultivated soils (derived both by pooling all data and by using a single T2 or T3 point), with their respective standard deviations. In this table the means for the data that were transformed are obviously transformed means. Table E2 shows means that, where necessary, were back-transformed from Table E1, so that they could be expressed in original units.

Figure 6-2: Control and cultivated means, standard deviation and 95% confidence intervals for organic carbon (g $100g^{-1}$) for farms Au, Ha, Sa, Sh, Ab and Mu

```
                                             Individual 95% CIs For Mean
                                             Based on Pooled StDev
Level       N     Mean      StDev    -----+---------+---------+---------+-
Au         10     1.22       0.40                  (---*----)
Au c       10     1.69       0.35                           (----*---)
Ha         10     1.06       0.17               (---*----)
Ha c       10     1.57       0.50                         (---*----)
Sa         10     0.94       0.32            (----*---)
Sa c       10     1.46       0.53                       (---*----)
Sh         10     0.67       0.18       (---*----)
Sh c       10     1.52       0.65                        (---*----)
Ab         10     0.71       0.21        (---*----)
Ab c       10     0.79       0.29         (----*---)
Mu         10     0.51       0.15    (---*----)
Mu c       10     0.52       0.16   (----*---)
                                     -----+---------+---------+---------+-
Pooled StDev = 0.36                     0.50      1.00      1.50      2.00
```

'Au' = Audu's cultivated soil. 'Au c' = Audu's control soil, etc. 'N' = number of replicates. 'Mean' and 'StDev'= mean and standard deviation for a particular soil. The figure next to these data represents a plot of the relative positions of the means to one another (the means are marked with an asterisk) and the 95% Confidence Intervals (marked with brackets around the mean).

Figure 6-3: Control and cultivated means, standard deviation and 95% confidence intervals for total nitrogen (Log10(100*g 100g^{-1})) for farms Au, Ha, Sa, Sh, Ab and Mu

```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N     Mean      StDev  ---------+---------+---------+-------
Au         10    1.11      0.19                        (---*----)
Au c       10    1.19      0.08                            (---*----)
Ha         10    1.01      0.05                   (----*---)
Ha c       10    1.09      0.17                       (----*---)
Sa         10    0.91      0.17              (----*---)
Sa c       10    1.05      0.17                     (----*---)
Sh         10    0.92      0.08              (----*----)
Sh c       10    1.06      0.19                     (----*----)
Ab         10    0.83      0.12          (----*---)
Ab c       10    0.84      0.21          (----*----)
Mu         10    0.77      0.14       (---*----)
Mu c       10    0.72      0.11    (----*----)
                                   ---------+---------+---------+-------
Pooled StDev = 0.15                       0.80      1.00      1.20
```

Figure 6-4: Control and cultivated means, standard deviation and 95% confidence intervals for pH for farms Au, Ha, Sa, Sh, Ab and Mu

```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N     Mean      StDev  ---+---------+---------+---------+---
Au         10    6.61      0.29                         (---*----)
Au c       10    6.03      0.55             (----*---)
Ha         10    6.62      0.11                         (---*----)
Ha c       10    6.46      0.13                      (---*----)
Sa         10    5.95      0.23           (----*----)
Sa c       10    6.42      0.15                     (---*----)
Sh         10    6.44      0.27                     (----*---)
Sh c       10    6.38      0.46                    (----*---)
Ab         10    6.44      0.22                     (----*---)
Ab c       10    6.31      0.59                   (---*----)
Mu         10    5.92      0.45           (---*----)
Mu c       10    5.58      0.46    (----*---)
                                   ---+---------+---------+---------+---
Pooled StDev = 0.36                 5.50      6.00      6.50      7.00
```

Figure 6-5: Control and cultivated means, standard deviation and 95% confidence intervals for exchangeable sodium (Log10(100*cmol$_{(c)}$ kg^{-1})) for farms Au, Ha, Sa and Sh

```
                             Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N     Mean      StDev  ---------+---------+---------+-------
Au         10    1.92      0.09           (-----*----)
Au c       10    1.96      0.16             (----*-----)
Ha         10    2.35      0.30                          (----*-----)
Ha c       10    2.04      0.31               (-----*-----)
Sa         10    2.30      0.40                        (-----*----)
Sa c       10    2.08      0.38                 (----*-----)
Sh         10    2.07      0.15                (-----*-----)
Sh c       10    1.70      0.14    (-----*----)
                                   ---------+---------+---------+-------
Pooled StDev = 0.27                       1.80      2.10      2.40
```

Figure 6-6: Control and cultivated means, standard deviation and 95% confidence intervals for exchangeable potassium (Log10(100*cmol$_{(c)}$ kg^{-1})) for farms Au, Ha, Sa and Mu

```
                                  Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N    Mean      StDev   --------+---------+---------+--------
Au         10    1.82      0.04                (-------*-------)
Au c       10    1.87      0.15                    (-------*-------)
Ha         10    1.79      0.23              (-------*-------)
Ha c       10    1.97      0.25                          (-------*-------)
Sa         10    1.79      0.16              (-------*-------)
Sa c       10    1.93      0.23                        (-------*-------)
Sh         10    1.66      0.10     (-------*-------)
Sh c       10    1.80      0.23               (-------*-------)
                                   --------+---------+---------+--------
Pooled StDev = 0.19                      1.65      1.80      1.95
```

Figure 6-7: Control and cultivated means, standard deviation and 95% confidence intervals for exchangeable calcium (Sqrt(100*cmol$_{(c)}$ kg^{-1}))for farms Au, Ha, Sa and Sh

```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N     Mean      StDev  ------+---------+---------+---------+
Au         10    36.67      2.29                          (----*----)
Au c       10    37.32      4.07                           (----*----)
Ha         10    33.78      2.27                     (----*----)
Ha c       10    32.35      8.09                   (----*----)
Sa         10    34.21      3.90                      (----*----)
Sa c       10    32.63      5.40                   (----*-----)
Sh         10    23.66      4.40    (----*-----)
Sh c       10    26.79      6.12         (-----*----)
                                   ------+---------+---------+---------+
Pooled StDev = 4.92                    24.0      30.0      36.0      42.0
```

Figure 6-8: Control and cultivated means, standard deviation and 95% confidence intervals for exchangeable magnesium (Log10(100*cmol$_{(c)}$ kg^{-1})) for farms Au, Ha, Sa and Sh

```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N    Mean      StDev   -------+---------+---------+---------
Au         10    2.22      0.04              (-----*-----)
Au c       10    2.39      0.14                         (-----*-----)
Ha         10    2.34      0.12                      (-----*-----)
Ha c       10    2.33      0.24                      (-----*----)
Sa         10    2.11      0.12       (-----*-----)
Sa c       10    2.17      0.08           (-----*-----)
Sh         10    2.09      0.07     (-----*-----)
Sh c       10    2.19      0.19            (-----*-----)
                                   -------+---------+---------+---------
Pooled StDev = 0.14                     2.10      2.25      2.40
```

Figure 6-9: Control and cultivated means, standard deviation and 95% confidence intervals for cation exchange capacity ($cmol_{(c)}$ kg^{-1}) for farms Au, Ha, Sa and Sh

```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N    Mean       StDev  -------+---------+---------+---------
Au         10    14.05      1.22                     (-----*----)
Au c       10    14.76      1.30                        (----*-----)
Ha         10    13.00      1.41                  (----*-----)
Ha c       10    12.63      4.09                 (----*-----)
Sa         10     8.81      2.18    (----*-----)
Sa c       10    10.17      3.12        (-----*----)
Sh         10     8.67      2.93   (-----*----)
Sh c       10    10.37      2.83         (-----*----)
                                   -------+---------+---------+---------
Pooled StDev = 2.57                     9.0      12.0      15.0
```

Figure 6-10: Control and cultivated means, standard deviation and 95% confidence intervals for available phosphorus (Sqrt(mg $100g^{-1}$)) for farms Au, Ha, Sa and Sh

```
                                  Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N    Mean      StDev   -----+---------+---------+---------+-
Au         10    2.44      1.23              (----*----)
Au c       10    2.44      1.65              (----*----)
Ha         10    1.24      0.46    (----*----)
Ha c       10    1.66      0.68        (----*----)
Sa         10    3.81      0.95                          (----*----)
Sa c       10    2.73      0.74                 (----*----)
Sh         10    2.35      0.58             (-----*----)
Sh c       10    2.39      0.94              (----*----)
                                   -----+---------+---------+---------+-
Pooled StDev = 0.97                    1.2       2.4       3.6       4.8
```

Figure 6-11: Control and cultivated means, standard deviation and 95% confidence intervals for available iron (Log10(mg kg^{-1})) for farms Au, Ha, Sa, Sh and Ab

```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level        N      Mean     StDev  ---------+---------+---------+-------
Au          10      1.77      0.06                          (--*---)
Au c        10      1.83      0.15                             (---*--)
Ha          10      1.45      0.07          (--*---)
Ha c        10      1.43      0.16         (---*--)
Sa          10      1.33      0.08    (--*---)
Sa c        10      1.31      0.17   (--*---)
Sh          10      1.43      0.15         (--*---)
Sh c        10      1.46      0.12           (--*---)
Ab          10      1.56      0.06               (---*---)
Ab c        10      1.57      0.07                (--*---)
                                   ---------+---------+---------+-------
Pooled StDev = 0.12                      1.40      1.60      1.80
```

Figure 6-12: Control and cultivated means, standard deviation and 95% confidence intervals for available manganese (mg kg^{-1}) for farms Au, Ha, Sa, Sh and Ab

```
                                Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level        N      Mean     StDev  --+---------+---------+---------+----
Au          10     43.52     10.31               (-----*-----)
Au c        10     45.10     21.78                (-----*-----)
Ha          10     40.04      5.09             (-----*-----)
Ha c        10     61.50     17.11                            (----*-----)
Sa          10     23.00      6.94    (----*-----)
Sa c        10     34.41     10.23           (-----*----)
Sh          10     36.44      7.26            (-----*-----)
Sh c        10     46.50     14.87                  (-----*-----)
Ab          10     48.04     20.37                   (-----*-----)
Ab c        10     53.34     21.66                       (----*-----)
                                    --+---------+---------+---------+----
Pooled StDev = 14.87                 16        32        48        64
```

Figure 6-13: Control and cultivated means, standard deviation and 95% confidence intervals for available zinc (Sqrt(mg kg^{-1}))for farms Au, Ha, Sa, Sh and Ab

```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N     Mean      StDev  ---------+---------+---------+-------
Au         10     3.48      0.69                      (----*-----)
Au c       10     3.67      0.86                        (-----*-----)
Ha         10     2.80      0.36           (-----*-----)
Ha c       10     4.02      0.86                            (-----*-----)
Sa         10     3.40      0.40                     (-----*----)
Sa c       10     3.79      1.00                          (----*-----)
Sh         10     3.32      0.62                    (-----*----)
Sh c       10     2.18      0.71   (-----*-----)
Ab         10     3.36      0.83                    (-----*-----)
Ab c       10     3.05      0.83                (-----*-----)
                                   ---------+---------+---------+-------
Pooled StDev = 0.74                       2.40      3.20      4.00
```

Figure 6-14: Control and cultivated means, standard deviation and 95% confidence intervals for available copper (mg kg^{-1}) for farms Au, Ha, Sa, Sh and Ab

```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N     Mean      StDev  ---+---------+---------+---------+---
Al         10     2.55      0.13                            (----*---)
Al c       10     2.55      0.08                            (----*---)
Aw         10     2.56      0.18                            (----*----)
Aw c       10     2.52      0.25                           (---*----)
Ha         10     2.14      0.14         (----*----)
Ha c       10     2.08      0.03      (----*----)
Sh         10     2.43      0.12                       (---*----)
Sh c       10     2.03      0.20    (----*----)
Ah         10     2.58      0.10                             (----*----)
Ah c       10     2.42      0.13                      (----*----)
                                   ---+---------+---------+---------+---
Pooled StDev = 0.15                  2.00      2.20      2.40      2.60
```

Figure 6-15: Control and cultivated means, standard deviation and 95% confidence intervals for available nickel (Log10(100*mg kg^{-1})) for farms Au, Ha, Sa, Sh and Ab

```
                                  Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N    Mean      StDev   ----+---------+---------+---------+--
Au         10    1.87      0.07                         (----*----)
Au c       10    1.96      0.05                            (----*-----)
Ha         10    1.59      0.09                (----*----)
Ha c       10    1.67      0.20                   (----*----)
Sa         10    1.28      0.26     (----*----)
Sa c       10    1.25      0.51    (----*----)
Sh         10    1.47      0.22            (----*----)
Sh c       10    1.41      0.18          (----*----)
Ab         10    1.53      0.17              (----*----)
Ab c       10    1.44      0.31           (----*----)
                                   ----+---------+---------+---------+--
Pooled StDev = 0.24                  1.20      1.50      1.80      2.10
```

Figure 6-16: Control and cultivated means, standard deviation and 95% confidence intervals for available cadmium (Log10(100*mg kg^{-1})) for farms Au, Ha, Sa, Sh and Ab

```
                                Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  --+---------+---------+---------+----
Au         10    1.05      0.25                (----*---)
Au c       10    1.47      0.10                              (----*---)
Ha         10    0.86      0.11          (----*---)
Ha c       10    1.01      0.15               (----*---)
Sa         10    0.92      0.09            (----*---)
Sa c       10    0.93      0.26            (----*----)
Sh         10    0.99      0.24               (---*----)
Sh c       10    0.71      0.35     (----*---)
Ab         10    1.27      0.09                        (---*----)
Ab c       10    0.78      0.32       (----*----)
                                   --+---------+---------+---------+----
Pooled StDev = 0.22                0.60      0.90      1.20      1.50
```

Figure 6-17: Control and cultivated means, standard deviation and 95% confidence intervals for available lead (Log10(100*mg kg^{-1})) for farms Au, Ha, Sa, Sh and Ab

```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level        N      Mean     StDev  -+---------+---------+---------+-----
Au          10      2.43      0.31        (---*--)
Au c        10      2.16      0.48   (--*---)
Ha          10      2.70      0.09             (---*---)
Ha c        10      2.93      0.49                  (---*--)
Sa          10      2.72      0.23              (--*---)
Sa c        10      2.82      0.18                (--*---)
Sh          10      3.41      0.26                           (---*---)
Sh c        10      3.26      0.23                         (--*---)
Ab          10      2.70      0.14             (---*---)
Ab c        10      2.66      0.22             (--*---)
                                   -+---------+---------+---------+-----
Pooled StDev = 0.29               2.00      2.50      3.00      3.50
```

6.1.2 Discussion

The first step towards an understanding of the sustainability of the agricultural system consists of rating the nutrient status of each farm using the overall means, without considering statistical differences between farms. This is because a statistically significant difference between two farms may not necessarily be important from an agricultural standpoint (i.e. it will not influence crop growth). Thus, the assessment of the productivity of each farm (i.e. "*The capacity of a soil to produce a certain yield of agronomic crops, or other plants, with optimum management*"—Foth and Ellis, 1997, p.2) should be made by gauging the soil fertility levels from a practical perspective (i.e. what does a certain level mean in terms of fertiliser requirement?), without consideration of how and why the various nutrients are at certain levels. Soil fertility has been defined as: "*The status of a soil with respect to its ability to supply elements essential for plant growth without a toxic concentration of any element*" (Foth and Ellis, 1997, p. 1).

Table 6-2 summarises the nutrient status of each farm, using the ratings given by two sources, Landon (1984) and MAFF (2000). It must be cautioned that MAFF (2000) ratings were determined for temperate UK soils and, therefore, are not strictly appropriate for the Jos Plateau soils. Unfortunately, there is no suitable equivalent work for tropical soils (apart from some information in Landon (1984), which has been incorporated appropriately into the discussion). Nevertheless, the ratings can be considered adequate for the purpose of providing a general framework. The data used to create a general assessment for each farm derive from the mean values presented in Table E2 in Appendix E. The issue was whether to use an average mean obtained from the pooled data across time or whether to use a single time point (T2 or T3—see 4.5.2 for explanation on why samples were not always represented by the same time point). The latter course was chosen as it can be related to the Figures in section 6.1.1. For the most part, the choice of one or the other method does not really change the broad categories. The control soils for each farm were also given a rating. The ratings have been discussed in combination with the statistical analyses in section 6.2, and it is useful to reiterate the importance of soil variability as a complicating factor. The EEC recommends that representative soil samples for fertiliser analysis should be made up by mixing 25 core samples taken from an area not exceeding 5ha, that is farmed for the same purpose (Council Directive 86/278/EEC). It is clear that the average value of several cores may or may not be an adequate descriptor of a field's nutrient status, because it allows the average determination of different variables but does not reflect the 'patchiness' of the concentration of these variables across the field. Yet, in some instances, these generalisations are necessary because highly targeted fertiliser recommendations are not always logistically possible. The ten replicate cores per farm in this research project were not made up to a composite core, they were deliberately kept separate to allow the detection of spatial differences. The ratings provided by various sources (Landon, 1984; MAFF, 2000) to classify soils into 'poor', 'medium', 'rich', or into indexes, are based on controlled field trials and frequently pinpoint cut-off levels where a response to fertiliser may be likely or unlikely, under certain conditions. Yet, so many factors play a role in defining a plant's response to fertiliser (environmental conditions, the plant's preferences, etc.), and it is clear that there can never be an exact cut-off level. The variability of soils is such that although statistical analyses may not differentiate between two fields because of the wide range of values, their mean values may actually fall into different 'categories' on which different recommendations will be made. Conversely, two fields may fall in the same category (perhaps having mean values close to the lower and upper boundary of the category, respectively), but may in effect be distinct from a statistical standpoint. Therefore, the two methods are complementary. It is useful to use the mean values for an overall fertiliser recommendation, but the statistical analysis can illustrate whether there is a problem with spatial variability.

Table 6-2: Nutrient ratings of the average values of the six farms in Delimi

Variable		*Au*	*Ha*	*Sa*	*Sh*	*Ab*	*Mu*
[a]Org. C	**T2**	Very low	Very low	Very low	Very low	Very low	Very low
	Cont	Very low	Very low	Very low	Very low	Very low	Very low
[a]Tot. N	**T2**	Low	Low	Very low	Very low	Very low	Very low
	Cont	Low	Low	Low	Low	Very low	Very low
pH	**T2**	Slightly acidic	Slightly acidic	Moderately acidic	Slightly acidic	Slightly acidic	Moderately acidic
	Cont	Moderately acidic	Slightly acidic	Slightly acidic	Slightly acidic	Slightly acidic	Moderately acidic
[b]Ex. K	**T3**	Index 3	Index 3	Index 3	Index 2	-	-
	Cont	Index 3	Index 4	Index 3	Index 3	-	-
[a]Ex. Ca	**T3**	High	High	High	Medium	-	-
	Cont	High	High	High	Medium	-	-
[a]Ex. Mg	**T3**	High	High	High	High	-	-
	Cont	High	High	High	High	-	-
[a]CEC	**T3**	Low	Low	Low	Low	-	-
	Cont	Low	Low	Low	Low	-	-
[b]Avail.P	**T2**	Index 5	Index 3	Index 7	Index 5	-	-
	Cont	Index 5	Index 4	Index 6	Index 5	-	-

Source—[a]Landon, 1984; [b]MAFF (2000). T2=Mean of cultivated soil samples at time point 2, approximately December-January; T3=Mean of cultivated soil samples at time point 3, approximately April-May; Cont=Mean of control soil samples, approximately December-January.

The interpretation of **organic C** is quite general. Usually organic C is taken as an indication of the organic matter content in the soil, which in turn is a crude measure of soil fertility. According to Landon (1984), organic C should be considered very low in all six farms and in all six controls (<2% very low).

Nitrogen measurements are also generally difficult to interpret because there are various forms of N present in the soil. Although soil analyses for N are routinely carried out, detailed recommendations can really only be made with detailed field trials, when leaf analysis and crop yield data are available (Landon, 1984). MAFF (2000) instead use a combination of soil type, previous crop planted, planned crop, and previous seasonal rainfall, to gauge the amount of N fertiliser needed, rather than use soil N data. As already discussed in 4.4.2, NO_3-N is considered a reliable measure of available N but the need for rapid pre-treatment to stop mineralisation (Danke and Johnson, 1990) precluded its use in this thesis work. Thus, Landon's (1984) ratings for **total** N by the Kjeldahl method can be used but should be considered a very general assessment. Using these ratings (<0.1% very low; 0.1-0.2% low; 0.2-0.5% medium; 0.5-1.0% high; >1.0% very high), it would appear that Au and Ha's cultivated and control soils should be rated as low, Ab and Mu's cultivated and control should be rated as very low, whilst Sa and Sh's cultivated are very low and the control low.

From the N and organic C data, it is possible to calculate the **C:N ratio** of the soil. Typically, the C:N ratio of cultivated surface (Ap horizon) soils ranges from 8:1 to 15:1, the median being near 12:1 (Brady and Weil, 1999) and, indeed, the soils in the study area have C:N ratios between 8:1 and 13:1, with a tendency for the control soils to have a slightly higher ratio than cultivated soils. This is, in all probability, caused by the marked decrease in organic C levels in the cultivated soils in respect to the controls (Figure 6-2), in contrast to the relatively smaller decrease in total N levels (Figure 6-3). The C:N ratio is usually taken as a measure of the organic matter in the soil and, in particular, the degree of humification (Landon, 1984). The C:N ratio can be strongly affected by management practices: for example the incorporation of partially decomposed straw residues tends to increase it, whereas legume residues that are high in N tend to reduce it (Landon, 1984). Generally, if the C:N ratio of the organic material added to the soil is more than 25:1, then soil microbes will have to scavenge the soil solution to obtain enough N. Therefore, the incorporation of high C:N residues will deplete the soil of soluble N, inducing N deficiency in higher plants, at least initially. Subsequently, when the activities of the decay micro-organisms subside because of lack of easily oxidizable C, their numbers will decrease, thus CO_2 formation will drop off and N demand will become less acute. At this point, as the decay of the organic material proceeds the C:N ratio decreases and once it drops below 20, it is expected that mineral N will begin to be released (Brady and Weil, 1999).

pH is an important variable to consider because it affects the availability of nutrients. For example, N availability tends to be greatest between pH 6 and 8 because nitrification is at its maximum, while the availability of P is reduced in acid soils because it tends to precipitate and be adsorbed by Fe and Al (Foth and Ellis, 1997), and in alkaline soils because it precipitates with $CaCO_3$ (Brady and Weil, 1999). The most favourable pH for phosphate availability is between 6.5 and 7.5, Ca and Mg tend to be deficient in acid soils, while Fe and Mn availability tends to fall with increasing pH (MAFF, 1981). Manganese and Al tend to be present in toxic quantities in very acid soils, when the pH is below 4.5 (Landon, 1984). Copper availability is not as clearly related to pH as the other elements, as deficiencies can occur in both acid and alkaline soils; the effects of toxic metals are minimised at pH 7, but if their levels are high, little can be done to the soil to overcome the problem (MAFF, 1981). MAFF (2000) consider the optimum pH (measured with a 1:2.5 water suspension) for continuous arable cropping on mineral soils to be 6.5, although they and other authors are aware that the ideal pH will depend on the crop's pH preference and the soil type. Indeed, for some soils, raising the pH above 6.5 by liming can result in a reduction in the availability of nutrients such as P, Mg and other micronutrients (Prasad and Power, 1997). Landon (1984) acknowledges the variation in pH tolerance of different plants but suggests that a range between 6.3 and 7.5 is suitable for most commercial crops. In the light of this information, Au and Ha can be rated as highly suitable for crop growth as the pH is 6.6, Sh and Ab are suitable as pH is 6.4, while Sa and Mu (6.2 and 6.0, respectively) are slightly acidic soils (see Table E2). This assessment in reality obscures the fact that the pH is subject to wide fluctuations throughout the farming season (see 6.2.4).

The **Na values** presented in Table E2 (Appendix E) represent the sum of exchangeable Na and soluble Na. Usually, both extracted and soluble Na would be determined to calculate the correct figure for exchangeable Na. However, the determination of soluble Na was omitted, because salinisation is not likely to be a problem in this area as total extractable Na is low, particularly when compared to the exchangeable Ca and Mg, the electrical conductivity is extremely low at <0.5dS m^{-1} (4.4.2.8) and pH is less than 8.5. Additionally, rainfall (annual average: 1,413mm—Alford *et al.*, 1979) plus irrigation exceed evapotranspiration, so that soluble Na is leached out of the soil profile (Alexander, Pers. Comm.). As Na is not an essential plant nutrient and is detrimental only if present in large quantities relative to the other cations, it is not of much interest in this research (and therefore is not displayed in Table 6-2).

The interpretation of K is complicated, and Landon (1984) warns that **exchangeable K** levels are of limited value to predict crop responses. This is because they only indicate immediately available K but do not give an indication of the capacity of the soil to release K over a longer period of time, a property linked to clay mineralogy. Unfortunately, there is no widely accepted test that measures exchangeable K, plus some index of the rate of K release. Furthermore, K is also known to change as a result of air-drying. It is found that, generally, samples with large amounts of available K (>1cmol$_{(c)}$ kg^{-1} of soil) tend to lose some by fixation, and samples with smaller amounts (<1 cmol$_{(c)}$ kg^{-1} of soil) tend to have their exchangeable K augmented from sources that are not available in the field (Landon, 1984). Nevertheless, MAFF (2000) provide a guide to estimating the requirement for K fertiliser by assigning an index number to the soil (depending on the levels of K), and associating it to the specific needs of each crop. It is difficult to generalise with the index values, because the crops vary strongly in their K requirements. An index of 2 (e.g. Sh's farm) will result in the application of 50-100kg

ha^{-1} of potash for optimal growth of beans, 100-150kg ha^{-1} for lettuce, onions and leeks, 125-175kg ha^{-1} for carrots, 150-200kg ha^{-1} for cabbage and beetroot, 300-350kg ha^{-1} for celery. An index of 3 (the other three farms) will result in no potash application for beans, lettuce, onions, and leeks, 35kg ha^{-1} for carrots, 60kg ha^{-1} for cabbage and beetroot, and 210kg ha^{-1} for celery. The control soils are rated as equal to cultivated in Au and Sa's situation, but are one class higher than the cultivated in Ha and Sh's case. A different way of interpreting the K values is given in Table 7.10 in Landon (1984; p. 126). Using the row of data from Malawi soils (from work by Young and Brown, 1962), then the four farms (both cultivated and control) can be considered to be high in available K (0.4-0.8$cmol_{(c)}$ kg^{-1}). Landon's conclusion was that, subject to soil texture, the environment, and the crop, a response to K fertiliser was unlikely in soils above 0.4$cmol_{(c)}$ kg^{-1}.

The **exchangeable Ca** measurements cannot be interpreted in any meaningful way. An examination of Table 5-8 immediately shows how high exchangeable Ca levels were in respect to the CEC (in some cases, the exchangeable Ca alone was more than the CEC value). This meant that frequently the total exchangeable bases (TEB) surpassed the CEC, and so base saturation (BS= TEB/CEC*100) was over 100% (data not shown). High levels of Ca are usually caused by the presence of Ca carbonates in the soils, but in soils with a pH<7, calcium and magnesium carbonates are seldom present (Landon, 1984). This was confirmed by treating samples of soil with dilute hydrochloric acid, and as they did not evolve CO_2, free carbonates could not be present. Thus, the high levels of Ca are probably caused by free, soluble Ca, derived from an alternative source: the irrigation water, the ash or possibly the Harmattan dust, which can bring large quantities of Ca, Mg and K (Harris, 1998). It seems improbable that the irrigation water is solely responsible, as Table 6-18 shows that there are large quantities of *all* the base cations (in approximately equal proportions) in the river water, and thus the dominance of Ca over the other cations in the soil cannot be explained. Ash samples instead consist of high proportions of base cations but are definitely dominated by total Ca (Table 7-1). Landon concluded that if soluble Ca or carbonates were present in the soil then any value that was above 10$cmol_{(c)}$ kg^{-1} could be considered high. This is the case for Au, Ha, Sa but not Sh (Table E2). Cultivated and control soils are ranked in a similar way for each individual farm.

As in the case of exchangeable Ca, it is likely that the measurement of **exchangeable Mg** was affected by the presence of soluble Mg. Although the measured levels are considerably lower than the levels of Ca, the range of 1.20 to 2.45$cmol_{(c)}$ kg^{-1} is particularly high and no response to Mg fertiliser is likely. Landon (1984) suggests that any value above 0.5$cmol_{(c)}$ kg^{-1} of soil should be considered high.

It is, therefore, not possible to provide accurate values for **exchangeable Ca** and **Mg**. Even if soluble Ca or Mg are measured and subtracted from the apparent exchangeable Ca and Mg measurements, the procedure is invalid because the two methods extract different amounts of soluble cations (Landon, 1984). Thus, these measurements are of little use for predicting a deficiency. Nevertheless, a Ca deficiency in these particular soils is unlikely because it usually only occurs in soils of low CEC with a pH of less than 5.5, or in soils that have high pH levels and an excessive Na content (Landon, 1984). Magnesium is harder to interpret, both because the actual exchangeable levels cannot be determined, and also because deficiencies can be caused not only by absolute low levels but by the association with high levels of other cations. For example, there is a tendency towards decreasing availability of Mg where the exchangeable Ca:Mg ratio exceeds 5:1, although the range of Ca:Mg ratios at which a soil remains fertile is quite wide (Landon, 1984).

The interpretation of **cation exchange capacity** (CEC) results can be problematic. Landon (1984) warns that the measurement of CEC can be subject to variability, depending on the pH, the concentration of the leaching solution used, and the type of clay minerals in the soil. Thus, the ratings he gives for top-soil CEC should be considered approximate (Landon, 1984, p.120). Soils with less than 5cmol$_{(c)}$ kg^{-1} are rated as very low, soils from 5 to 15cmol$_{(c)}$ kg^{-1} are rated as low, soils from 15 to 25cmol$_{(c)}$ kg^{-1} are rated as medium, soils from 25 to 40cmol$_{(c)}$ kg^{-1} are high and soils with more than 40cmol$_{(c)}$ kg^{-1} are rated as very high. FAO (1979) considers values of CEC between 8 and 10cmol$_{(c)}$ kg^{-1} as indicative minimum values in the top 30cm of soil for satisfactory production under irrigation, provided other factors are favourable. At T3 all four soils are above 8cmol$_{(c)}$ kg^{-1}, and, in fact, Ha and Au are above 10 (Table E2). According to Landon's classification though, all four soils (cultivated and control) should be rated as low.

Little can be said about the **base saturation** (BS) of the soils because of the excess amounts of soluble Ca. The levels of Ca are so high that the exchange complex is likely to be dominated by this element. Often, in Au and Ha's samples, the total exchangeable bases (TEB) exceeded the CEC so that effectively the cation exchange complex had to be base saturated (BS= 100%), while for Sa and Sh, the BS tended to be lower but always above 60%. With a BS of about 60%, these soils are deemed to be eutric (FAO-Unesco, 1974).

Available P levels were assessed according to MAFF (2000) guidelines. Each soil is given an index, depending on the amount of P in the soil. MAFF then determines the requirement for P fertiliser, for different crop types, with the help of the soil index. Ha's farm has an index 3, e.g. a 100kg ha^{-1} of P_2O_5 would have to be applied, to successfully grow crops such as lettuce, cabbage and celery, whilst beans, onions, leeks, beetroot and carrots only require 50kg ha^{-1} of P_2O_5. The remaining farms (Au, Sh, and Sa) have an index of 5 or more, requiring no P fertiliser because there are large reserves of the nutrient in the soil. It is noteworthy that in Au and Sh's farms, the cultivated and control soils have the same index, but in Ha's farm the control is one index above the cultivated, and in Sa's farm it is the opposite (Table 6-2). Landon (1984) translates MAFF's figures to fertiliser response: likely—when levels are low, i.e.<2ppm; probable—when levels are medium, i.e. 2-40ppm; unlikely—when levels are high, i.e. >40ppm. It must be remembered that, as in the case of K, the measurement of available P does not provide any indication of the soil's release of P over a longer period of time and, unfortunately, there is no widely accepted test that provides an indication of immediately and slower-release P.

Alongside the requirement for primary (N, P and K) and secondary (Ca, Mg and S) nutrients, plants also have a requirement for certain essential trace elements or micronutrients (Prasad and Power, 1997). Of the seven metals tested in the research project, five are essential micronutrients for plant growth: **Fe, Mn, Zn, Cu and Ni**, but only the first four are unequivocally essential trace elements that are most likely to give rise to deficiency problems in the plants (Alloway, 1990). **Cadmium** and **Pb** are not essential, but these two elements and Ni are particularly hazardous to human health (Risser and Baker, 1990). Soil testing to establish a deficiency or toxicity for any particular trace element is subject to many uncertainties. These will be discussed below and, where possible, the available data will be interpreted in the light of previous studies.

The first uncertainty, when establishing potential toxicity problems, is related to the method used to determine the heavy metals in the soil. The problem hinges on the fact that depending on the extracting agent used, different critical levels will be established, and that the most common soil testing methods do not relate well to field calibration studies (Landon, 1984). In this research, diethylene-triamine-pentaacetic acid (DTPA) was chosen as the extracting agent and, as with other extracting agents there are controversies surrounding the use of it. Apart from the extractant used, a second factor that confounds the interpretation of heavy metal concentrations in the soil is the soil environment itself. It is known that the availability of heavy metals to plants in soil is strongly dependent on the pH, and it is generally found that the toxicity of various metals is reduced at higher pH (Williams, 1980; Alloway, 1990), and the harmful effects are also alleviated by higher amounts of organic matter (Williams, 1980; Webber, 1980a). It has also been suggested that the alleviation of heavy metal toxicity attributed to high contents of organic matter may actually be a result of high cation exchange capacity (CEC); certainly some studies have shown that soils with a higher CEC are less impacted than soils with a low CEC (Webber, 1980a). Furthermore, each element can be differently affected by a variety of factors. For example, deficiency conditions or contributory factors for Cu deficiency are low soil Cu, high soil P, high organic matter and N, high soil Zn and sandy texture (Landon, 1984, Table 7.26). Elements can interact with one another: for example, a study on Ni, Cu and Zn showed that generally the effects of the metals in combination tended to be additive (Davies, 1980), while other elements can be antagonistic (Prasad and Power, 1997). A third factor that will influence the dose-response curves for micronutrients (which will have both a lower and an upper critical concentration) or non-essential elements (which will only have the upper critical concentration), will be the sensitivity of each plant species. Plant species and their cultivars differ greatly in their sensitivity to both toxicities and deficiencies.

For all the reasons detailed above, the results on heavy metals in soil should be used as qualitative indicators of potential deficiencies and toxicities, and combined with data on crop tissue metal concentration (6.4). Table 6-3 has been created from various sources to illustrate the divergence between typical 'bioavailable' levels of elements in the soil, and regulatory maximum permissible 'total' levels. The first two columns have been adapted from Berrow and Burridge's (1980) table of typical levels of heavy metals in soil, extracted with 0.5M acetic acid and 0.05M EDTA. The other two columns represent maximum allowable concentrations in open spaces or agricultural soils according to ICRCL and the EEC, respectively. These are 'total' concentrations, except for those values marked with an asterisk that are based on EDTA-extractable values.

Table 6-3: Typical values of heavy metals extracted with 0.05M EDTA and 0.5M acetic acid and maximum permissible levels (total concentrations) according to ICRCL and the EEC (mg kg^{-1})

Element	[a]***Typical levels-EDTA extractable***	[a]***Typical levels-Acetic acid extractable***	[b]***ICRCL maximum allowable levels in an open space***	[c]***EEC maximum allowable levels in agricultural soils pH6-7***
Fe	100-3000	10-2000	-	-
Mn	5-100	5-100	-	-
Zn	<2-20	<2-30	280*	150-300
Cu	<0.3-10	<0.05-3.0	140*	50-140
Ni	0.1-5.0	0.2-5.0	35*	30-75
Cd	<0.01-0.3	<0.01-0.3	15	1-3
Pb	<0.002-4.0	1.0-10.0	1500	50-300

*Extractable levels by 0.05M EDTA.
Source—Adapted from [a]Berrow and Burridge, 1980; [b]ICRCL, 1987 as cited by Alloway, 1990; [c]Council Directive 86/278/EEC, Annex IA.

For all the reasons detailed so far, it is difficult to determine if the soils pose a potential problem in terms of either deficiency or toxicity from the soil data alone. Comparing data from Table E2 and Table 6-3 and making allowances for the fact that DTPA is reported to extract less than EDTA, (Quevauviller *et al.*, 1996) it appears that the soils in the farming area can be considered to be in the typical range for Fe (low end of the scale), Mn (mid-range), Zn (mid-range), Cu (low range), Ni (low range) and Cd (low to mid-range). Lead is in the typical range for all farms except Sh, who has unusually high levels. Thus, the data need to be correlated to further information about the situations that can be conducive to toxicity or deficiency of certain elements.

Soils in the study area are unlikely to be affected by either Fe or Mn deficiency or toxicity. In the case of Fe, toxicity is believed to be a rare problem (Landon, 1984), and there are probably no deficiency risks because the soil pH is below 7.0. Deficiencies tend to occur in fruit crops growing on calcareous soils (MAFF, 2000), while vegetables tend to be quite tolerant of low levels of Fe (Prasad and Power, 1997). Manganese deficiency commonly affects cereals, sugar beet and peas, and occurs in peaty, organic or sandy soils at high pH (MAFF, 2000). Manganese toxicity can instead occur in acid soils (Prasad and Power, 1997).

Zinc, Cu and Ni are well below the EDTA-extractable maximum allowable element concentrations in the UK, for non-calcareous soils (Alloway, 1990), and within Berrow and Burridge's (1980) 'typical' soil levels, so should not be present in toxic concentrations. Increasing research is strengthening the claim that Ni should be considered an essential plant nutrient (Prasad and Power, 1997), but it is not required in large quantities, so although Ni levels are very low in the study area, it should not pose a deficiency problem. It is not as simple to ascertain a potential Zn or Cu deficiency but both seem improbable. Possible deficiency levels for Zn extracted with DTPA are between 0.5 and 1.0ppm, although plants vary in their requirements as well as their abilities to extract Zn from the soil. Furthermore, zinc deficiency is quite common in calcareous soils but is rare in acid soils (Landon, 1984). Copper deficiencies are uncommon in vegetables except in lettuce and onion, but occur mainly in cereals on sands and peats, reclaimed heathland and shallow soils over chalk (MAFF, 1981).

The evaluation for potential Cd and Pb toxicity is affected by various factors. For example, cadmium levels would appear to be quite low but even low levels can result in high yield depressions depending on the crop species: for example, solution cultures containing 0.2μg Cd ml^{-1} are sufficient to cause a 50% yield depression in field beans, turnips and red beets, but 9.0μg Cd ml^{-1} are required to obtain a similar depression in cabbage (Bingham and Page, 1975). In the case of Pb there is no satisfactory extractant procedure to predict plant uptake, primarily because little is known about the factors that control availability of heavy metals at the root/soil interface. There is, though, a general agreement that only a small proportion of total Pb in the soil is available for uptake by plants because of its low solubility and mobility (Alloway, 1990). A complication for both metals is that available guidelines for maximum permissible levels in soil are based on a strong acid digestion, not on extractable levels. As there seems be quite good correlation between total and DTPA-extractable Cd levels, it can be argued that the DTPA-extractable values can be converted to 'total' levels by using the ratios quoted in the literature. The same exercise can be performed for Pb, but the literature seems to agree that DTPA is not a suitable extractant for Pb. Singh *et al.* (1998) found that 38% of 'total' Cd and 13% of 'total' Pb are DTPA-extractable, while Stephens *et al.* (2001) report values of more than 50% for Cd and 10-35% for Pb (upper part of the core). Using these references, if it is assumed that, on average, 45% Cd and 17% Pb are DTPA-extractable, the *highest* total concentrations for control and cultivated can be calculated and compared to the EEC limits set out in Council Directive 86/278/EEC. Ab's cultivated land can be estimated at 0.42mg Cd kg^{-1}, while Au's control contains 0.66mg Cd kg^{-1}. Sh's cultivated land can be estimated at 151mg Pb kg^{-1} and his control at 107mg Pb kg^{-1}, while the second highest values are 30.8mg Pb kg^{-1} for Sa's cultivated land, and 50mg Pb kg^{-1} for Ha's control. Following this procedure, neither Cd nor Pb estimated 'total' concentrations exceed the EEC maximum allowable levels. Sh's farm is the only one that gives cause for some concern. The estimated total Pb levels fall between the lower and upper EEC limits and as they are considerably higher than the other farms, it can only be speculated that some form of highly localised contamination occurred in previous years (it is difficult to establish what—maybe a batch of contaminated refuse ash). The analysis of the crop data can provide further information on the potential for Pb contamination on Sh's farm (6.4).

6.2 EXAMINING THE IMPACT OF SFM STRATEGIES ON THE SOIL IN THE LONG AND SHORT TERM

This section presents and discusses data on objectives III and IV. Although these two objectives are listed separately, they are, in fact, strongly linked and have been discussed together, and related to the mean data presented in the previous section (Figure 6-2 to Figure 6-17). The first sub-section reviews what objectives III and IV are about and recaps the key points of the statistical approaches. The second sub-section presents the outcome of the statistical analysis and is followed by the third discussion sub-section. The fourth sub-section relates some of the findings to soil texture and the final one discusses farmers' soil classification.

6.2.1 An overview

Objective III sought to examine the long-term impacts of cultivation practices on the soil by examining differences between cultivated and uncultivated (control) sites of each case study farm. The sampling strategy has been described at length in 4.2.6 and the model used to analyse the samples was a 'two-way analysis of variance' (4.5.2). This model can detect an overall 'Farm' effect (i.e. a difference between farms), an overall 'Status' effect (a difference between cultivated and uncultivated sites), and 'Farm*Status interaction' effect. If the 'Farm' effect resulted significant, it was followed up with Tukey's Honestly Significant Difference

(HSD) multiple comparison tests. As there were only two levels in the 'Status' effect (i.e. difference caused by the practice of cultivation), it was obviously unnecessary to carry out multiple comparison tests. If the 'Farm*Status' interaction effect was significant then the analysis of main effects (i.e. 'Farm' or 'Status') was essentially rendered meaningless (Sheskin, 1997) because it masks the fact that any one factor level may not be having the same effect across all levels of the other factor. Thus, Sheskin's (1997) alternative procedure of evaluating all levels of one factor across only one level of the other factor was adopted (see 4.5.2). This approach was applied to Au, Ha, Sa and Sh, and additionally to Ab and Mu, for a few select variables. The 'two-way anova' will be referred to as Model 1, in the remainder of the discussion section.

Objective IV sought to examine the impacts of cultivation practices over the course of one farming season (short-term effects). The assumption behind this idea was that if farmers were meeting crop demand with their SFM strategies, then nutrient levels, at the end of the season, would not be significantly different from levels at the beginning of the season. The very specific sampling strategy used to collect data to answer this objective has been described at length in 4.2.6, and is based upon a very specific analysis of variance (anova) model, the 'mixed two-factor within subjects anova design' (4.5.2). This model can detect overall differences between farms ('Farm' effect), overall changes over time ('Time' effect), and a 'Farm*Time interaction' effect, which, if significant, indicates that either the changes over time are not consistent across farms, or that differences between farms change at the different time points. Whenever, a 'Farm', 'Time', or 'Farm*Time' effect resulted in a significant difference, multiple comparisons were carried out according to the procedure outlined in Keppel (1991). This approach has been used with Au, Ha, Sa and Sh. From here onwards, to simplify the discussion, the 'mixed two-factor within subjects anova design' will be referred to as Model 2.

It is obvious that there is some degree of overlap between models, as both examine the differences between farms, but do so in a different way. Model 1 looks for differences between farms, averaging across cultivated and control soils for each farm. Model 2 looks for differences between farms, only looking at the cultivated soils. It pools the data for different time points, but they are always from the farmed soil. Clearly, some discrepancies between the models could be expected, but as section 6.2.3 shows, there is fairly good agreement between them.

6.2.2 Data

This section summarises the outcome of the statistical analyses used to address objective III (Table 6-4) and objective IV (Table 6-6). Where the outcome of the analysis for a particular variable was significant, it was followed up with multiple comparison tests according to the procedure described in 6.2.1, and these have been presented in Table 6-5 and Table 6-7, respectively.

Table 6-4: Results for various soil variables using two-way analysis of variance applied to control and cultivated soils of different farms

Variable tested	***Farm effect***		***Status effect***		***Farm*Status Interaction***	
	F test	***p value***	***F test***	***P value***	***F test***	***P value***
Org. C % or g $100g^{-1}$	19.05 (5,108)	<0.001	37.80 (1,108)	<0.001	3.65 (5,108)	0.004
Tot. N Log10(100*g $100g^{-1}$)	19.05 (5,108)	<0.001	5.87 (5,108)	0.017	1.25 (5,108)	N.S.
pH	11.62 (5,108)	<0.001	4.04 (1,108)	0.047	4.04 (5,108)	0.001
Ex. Na Log10(100*$cmol_{(c)}$ kg^{-1})	7.73 (3,72)	<0.001	12.90 (1,72)	0.001	2.35 (3,72)	N.S.
Ex. K Log10(100*$cmol_{(c)}$ kg^{-1})	2.46 (3,72)	N.S.	9.83 (1,72)	0.002	0.38 (1,72)	N.S.
Ex. Ca Sqrt(100*$cmol_{(c)}$ kg^{-1})	20.38 (3,72)	<0.001	0.03 (1,72)	N.S.	1.01 (3,72)	N.S.
Ex. Mg Log10(100*$cmol_{(c)}$ kg^{-1})	11.30 (3,72)	<0.001	6.48 (1,72)	0.013	1.23 (3,72)	N.S.
CEC $cmol_{(c)}$ kg^{-1}	18.23 (3,72)	<0.001	2.19 (1,72)	N.S.	0.63 (3,72)	N.S.
Avail. P Sqrt(mg $100g^{-1}$)	11.66 (3,72)	<0.001	0.53 (1,72)	N.S.	2.22 (3,72)	N.S.
Avail. Fe Log10(mg kg^{-1})	49.09 (4,90)	<0.001	0.34 (1,90)	N.S.	0.49 (4,90)	N.S.
Avail. Mn mg kg^{-1}	7.42 (4,90)	<0.001	11.22 (1,90)	0.001	1.28 (4,90)	N.S.
Avail. Zn Sqrt(mg kg^{-1})	4.39 (4,90)	0.003	0.24 (1,90)	N.S.	6.95 (3,90)	<0.001
Avail. Cu Log10(100*mg kg^{-1})	36.84 (4,90)	<0.001	19.03 (1,90)	<0.001	5.53 (4,90)	<0.001
Avail. Ni Log10(100*mg kg^{-1})	20.26 (4,90)	<0.001	0.00 (1,90)	N.S.	0.63 (4,90)	N.S.
Avail. Cd Log10(100*mg kg^{-1})	10.36 (4,90)	<0.001	0.80 (1,90)	N.S.	13.47 (4,90)	<0.001
Avail. Pb Log10(100*mg kg^{-1})	32.71 (4,90)	<0.001	0.15 (1,90)	N.S.	2.21 (4,90)	N.S.

Values in brackets in the F column are degrees of freedom.

Table 6-5: Outcome of multiple comparison tests carried out on terms that resulted significant in the two-way analysis of variance

Variable tested	*Farm effect*	*Status effect*	*Farm*Status Interaction*
Tot. N Log10(100*g $100g^{-1}$)	Mean order: Mu, Ab, Sa, Sh, Ha, Au Mu & Ab<Sa, Sh, Ha & Au Sa & Sh<Au	Cult<Cont	N.S.
Ex. Na Log10(100*$cmol_{(c)}$ kg^{-1})	Mean order: Sh, Au, Sa, Ha Sh & Au<Sa & Ha	Cont<Cult	N.S.
Ex. K Log10(100*$cmol_{(c)}$ kg^{-1})	Mean order: Sh, Au, Ha, Sa N.S.	Cult<Cont	N.S.
Ex. Ca Sqrt(100*$cmol_{(c)}$ kg^{-1})	Mean order: Sh, Ha, Sa, Au Sh<Ha, Sa & Au	N.S.	N.S.
Ex. Mg Log10(100*$cmol_{(c)}$ kg^{-1})	Mean order: Sh, Sa, Au, Ha Sh & Sa<Au & Ha	Cult<Cont	N.S.
CEC $cmol_{(c)}$ kg^{-1}	Mean order: Sa, Sh, Ha, Au Sa & Sh<Ha & Au	N.S.	N.S.
Avail. P Sqrt(mg $100g^{-1}$)	Mean order: Ha, Sh, Au, Sa Ha<Sh, Au & Sa Sh & Au<Sa	N.S.	N.S.
Avail. Fe Log10(mg kg^{-1})	Mean order: Sa, Ha, Sh, Ab, Au Sa<Ha & Sh Sa, Ha, Sh<Ab Sa, Ha, Sh, Ab<Au	N.S.	N.S.
Avail. Mn mg kg^{-1}	Mean order: Sa, Sh, Au, Ab, Ha Sa<Ab, Au & Ha	Cult<Cont	N.S.
Avail. Ni Log10(100*mg kg^{-1})	Mean order: Sa, Sh, Ab, Ha, Au Sa<Ab & Ha Sa, Sh, Ab, Ha<Au	N.S.	N.S.
Avail. Pb Log10(100*mg kg^{-1})	Mean order: Au, Ab, Sa, Ha, Sh Au<Ac, Sa, Ha & Sh Ab, Sa, Ha<Sh	N.S.	N.S.

Contd. ***Org. C*** % or g 100g^{-1}	**Farm*Status interaction** For Au: Cult<Cont For Ha: Cult<Cont For Sh: Cult<Cont For Sa: Cult<Cont At Control mean order: Mu, Ab, Sa, Sh, Ha, Au Mu & Ab<Sa, Sh, Ha & Au At Cultivated mean order: Mu, Sh, Ab, Sa, Ha, Au Mu, Sh & Ab<Ha & Au Mu<Sa
pH	**Farm*Status interaction** For Ha: Cont<Cult For Au: Cont<Cult For Sa: Cult<Cont At Control mean order: Mu, Au, Ab, Sh, Sa, Ha Mu<Ab, Sh, Sa & Ha At Cultivated mean order: Mu, Sa, Sh, Ab, Au, Ha Mu & Sa<Sh, Ab, Au & Ha
Avail. Zn Sqrt (mg kg^{-1})	**Farm*Status interaction** For Sh: Cont<Cult For Ha: Cult<Cont At Control mean order: Sh, Ab, Au, Sa, Ha Sh<Au, Sa & Ha At Cultivated mean order: Ha, Sh, Ab, Sa, Au N.S.
Avail. Cu Log10(100*mg kg^{-1})	**Farm*Status interaction** For Sh: Cont<Cult For Ab: Cont<Cult At Control mean order: Sh, Sa, Ab, Ha, Au Sh, Sa<Ab, Ha & Au At Cultivated mean order: Sa, Sh, Au, Ha, Ab Sa<Sh, Au, Ha & Ab
Avail. Cd Log10(100*mg kg^{-1})	**Farm*Status interaction** For Au: Cult<Cont For Ab: Cont<Cult For Ha: Cult<Cont For Sh: Cont<Cult At Control mean order: Sh, Ab, Sa, Ha, Au Sh, Ab, Sa, Ha<Au At Cultivated mean order: Ha, Sa, Sh, Au, Ab Ha, Sa, Sh, Au<Ab

Outcome of Tukey's multiple comparison tests carried out for the main effect terms which tested significant using two-way analysis of variance (Table 6-4). No multiple comparisons were carried out if the outcome of the test was non-significant (this is marked by a N.S. in the appropriate cell). Means are ordered from lowest to highest and (<) indicates which means are significantly lower. In the event of a significant 'Farm*Status Interaction', the results are presented exclusively in a single 'Farm*Status Interaction' column at the bottom of the Table (following the procedure in Sheskin, 1997).

Table 6-6: Results for various soil variables for four cultivated soils using a 'mixed two-factor within subjects analysis of variance design'

Variable tested	*Farm effect*		*Time effect*		*Farm*Time interaction*	
	F test	*p value*	*F test*	*p value*	*F test*	*p value*
Org. C g $100g^{-1}$ or %	5.01 (3,36)	0.005	4.20 (2,72)	0.019	1.47 (6,72)	N.S.
Tot. N Log10(100*g $100g^{-1}$)	4.11 (3,36)	0.013	1.09 (2,72)	N.S.	1.70 (6,72)	N.S.
pH	20.50 (3,36)	<0.001	11.72 (2,72)	<0.001	5.46 (6,72)	<0.001
Ex. Na Log10(100*$cmol_{(c)}$ Kg^{-1})	5.58 (3,36)	0.003	10.40 (3,36)	0.003	3.04 (3,36)	0.041
Ex. K Log10(100*$cmol_{(c)}$ kg^{-1})	2.11 (3,36)	N.S.	0.49 (1,36)	N.S.	0.78 (3,36)	N.S.
Ex. Ca Sqrt(100*$cmol_{(c)}$ kg^{-1})	34.25 (3,36)	<0.001	4.78 (1,36)	0.035	3.90 (3,36)	0.016
Ex. Mg Log10(100*$cmol_{(c)}$ kg^{-1})	33.15 (3,36)	<0.001	0.95 (1,36)	N.S.	0.93 (3,36)	N.S.
CEC $cmol_{(c)}$ kg^{-1}	31.02 (3,36)	<0.001	2.51 (1,36)	N.S.	1.97 (3,36)	N.S.
Avail. P Sqrt(mg $100g^{-1}$)	21.65 (3,36)	<0.001	1.88 (2,72)	N.S.	0.97 (6.72)	N.S.

Values in brackets in the F column are degrees of freedom.

Table 6-7: Outcome of multiple comparison tests carried out on terms in the 'mixed two-factor within subjects model' that resulted significant

Variable tested	*Farm effect*	*Time effect*	*Farm*Time interaction*
Org. C g $100g^{-1}$ or %	Mean order: Sh, Sa, Ha, Au Sh<Sa, Ha & Au	Mean order: T2, T1, T3 T3<T1 & T2	N.S.
Tot.N Log10(100*g $100g^{-1}$)	Mean order: Sh, Sa, Ha, Au Sh & Sa<Au	N.S.	N.S.
Ex. K Log10(100*$cmol_{(c)}$ kg^{-1})	Mean order: Sh, Sa, Ha, Au N.S.	N.S.	N.S.
Ex. Mg Log10(100*$cmol_{(c)}$ kg^{-1})	Mean order: Sh, Sa, Au, Ha Sh & Sa<Au & Ha Au<Ha	N.S.	N.S.
CEC $cmol_{(c)}$ kg^{-1}	Mean order: Sh, Sa, Ha, Au Sh & Sa<Ha & Au	N.S.	N.S.
Avail. P Sqrt(mg $100g^{-1}$)	Mean order: Ha, Au, Sh, Sa Ha<Au, Sh & Sa Ha, Au, Sh<Sa	N.S.	N.S.
pH	***Farm*Time interaction*** For Sh mean order: T1, T2, T3 T1<T3 For Ha mean order: T2, T1, T3 T2, T1<T3 For Sa mean order: T2, T1, T3 T2<T3 At T1 mean order: Sa, Sh, Au, Ha Sa, Sh & Au<Ha At T2 mean order: Sa, Sh, Au, Ha Sa<Sh, Au & Ha At T3 mean order: Au, Sa, Sh, Ha Au, Sa, Sh & Ha		
Ex. Na Log10(100*$cmol_{(c)}$ kg^{-1})	***Farm*Time interaction*** For Ha mean order: T1, T3 T1<T3 At T3 mean order: Au, Sh, Sa, Ha Au<Sa & Ha		
Ex. Ca Sqrt(100*$cmol_{(c)}$ kg^{-1})	***Farm*Time interaction*** For Sa mean order: T1, T3 T1<T3 At T1 mean order: Sh, Sa, Ha, Au Sh & Sa<Ha & Au At T3 mean order: Sh, Ha, Sa, Au Sh<Ha, Sa & Au Ha<Au		

Outcome of the multiple comparison tests carried out according to the procedure illustrated by Keppel (1991) for the terms that tested significant using a 'mixed two-factor within subjects analysis of variance design' (see Table 6-6). Further explanations can be found in Table 6-5.

6.2.3 Discussion

An inspection of Table 6-4 (Model 1) unsurprisingly reveals that there were differences between some farms in terms of soil type (denoted by a highly significant 'Farm' effect), and that cultivation was frequently having an impact on nutrient levels (as indicated by significant 'Status' effects), but that, sometimes, either cultivation was not having the same effects across farms, and/or differences between farms were not the same at the control and cultivated levels (as indicated by a significant 'Farm*Status interaction' effect).

In Model 2, the 'Farm' effect was significant across all variables except K (Table 6-6). The 'Time' effect is significant for four variables (organic C, pH, exchangeable Na and Ca) and, with the exception of organic C, the 'Farm*Time interaction' effect was also significant (Table 6-6).

The next subsection will combine the outcomes of Model 1 with Model 2 (where appropriate), and will also refer to the overall rating of the nutrient levels (see Table 6-2) of the farms, by two sources, Landon (1984) and MAFF (2000). For ease of reference, clear-cut, important points are marked with a ♦ symbol. Then will follow a discussion relating the chemical properties to texture (as this is frequently a controlling factor), and finally a subsection on farmers' soil classification. This is because although this research is seeking differences primarily in terms of chemical characteristics, farmers may use entirely different criteria in classifying their soils. Understanding these criteria may help improve the understanding of their SFM strategies.

6.2.3.1 Individual variables

With both Model 1 and Model 2, there were significant differences between farms in terms of **organic C**. ♦However, it is apparent from Table 6-2, that all farms (cultivated or control) are uniformly rated as very low (according to Landon, 1984). Therefore, although there are marked differences between farms from a statistical perspective, from a practical soil management perspective, they mean little. ♦What is important is that Model 1 detects that that there is a trend for cultivated soils to be significantly lower than control soils in the case of Au, Ha, Sa and Sh (Table 6-5) and this is visually quite obvious when Figure 6-2 is examined. ♦The 'Time' effect in Model 2 was significant and it was clear that, although at mid-season the organic C levels had dropped slightly in respect to T1, by T3 they had increased significantly both in respect to T1 and T2 (Table 6-7). This short-term trend runs counter to the finding in Table 6-5 where there seems to be a long-term decrease in organic C levels between the cultivated and the control soils.

For **total N**, Model 1 shows that Ab and Mu were significantly lower than Sa, Sh, Ha and Au, whilst Au was significantly higher than Sa and Sh (Table 6-5). This last finding is consistent with the results from Model 2 (Table 6-7). That Model 1 pools data from the cultivated and the control soils needs to be considered when examining Table 6-2. Indeed from Table 6-2, it would appear that Sa and Sh's soils differ markedly between control and cultivated, whereas Au, Ha, Ab and Mu show no difference. Yet, statistically Sa and Sh are grouped with Au and Ha. ♦Model 1 also highlights that cultivated soils are significantly lower than control soils, so cultivation is having an impact by reducing N levels, as is happening with organic C (see Figure 6-2 and Figure 6-3).

Although **pH** was examined with both Model 1 and Model 2, the discussion will be deferred to section 6.2.4, because, as introduced in 4.2.6, additional samples were collected for a more thorough analysis of seasonal fluctuations.

Exchangeable Na presents some significant results (Table 6-5 and Table 6-7), however, as the discussion in 6.1.2 shows that it is not likely to be present in quantities that are detrimental to plant growth and, in addition, there were anomalies with the results (see Appendix B), this variable is not discussed any further.

Exchangeable K provides results that are not matched by any other nutrient variable. ♦Overall, there are no significant differences between farms and this is reflected by the results of both models (Tables 6-5 and 6-7). ♦There is a definite trend across farms whereby cultivated soils are significantly lower than the controls (Table 6-5). Figure 6-6 indicates that this effect is less marked for Au. The decline in cultivated soils in respect to the controls is not matched by a short-term trend (Table 6-7). Exchangeable K is a good example of the problem discussed in 6.1.2, where statistically significant differences may not be reflected in the ratings based on mean values and *vice versa*. ♦In this case, although there are no significant differences between farms, the ratings in Table 6-2, which are based on mean values, can actually place some of the soils into different categories.

♦**Exchangeable Ca** levels are ranked as high across all farms (Table 6-2). ♦Model 1 shows that Sh is significantly lower than Sa, Ha and Au (Table 6-5) but as there is no significant 'Status' effect, controls and cultivated do not differ significantly in their levels for any of the farms (Figure 6-7). ♦In Model 2 the 'Farm*Time interaction' term was significant for exchangeable Ca (Table 6-6). At T1, Sh and Sa were significantly lower than Ha and Au, but by T3 only Sh was significantly lower than Ha, Sa and Au, and Ha was significantly lower than Au. This status shift is primarily caused by a significant increase in exchangeable Ca at T3 only for Sa (Table 6-7). This is a curious result, as there is no particular reason why such a large increase should occur only in Sa. Furthermore, Sa's pH values undergo a similar, unexpectedly, large rise by T3 (suggesting that these two increases are linked).

♦ In Table 6-2, for **exchangeable Mg**, both cultivated and control soils are classified as having high levels of Mg. Both models found that Sh and Sa are significantly different from Au and Ha (Table 6-5 and Table 6-7). Model 2, additionally, demonstrated that Au was significantly lower than Ha (in this instance obviously the control soils are excluded from the analysis). ♦ There were no seasonal short-term changes in Mg (Table 6-7) but ♦ there are some long-term effects of cultivation as in cultivated soils Mg levels are significantly lower than controls (Table 6-5). The inspection of Figure 6-8 would support this conclusion for Sh, Sa and particularly Au, but not for Ha, where control and cultivated soils overlap to a great extent.

♦ In Table 6-2, all soils are rated uniformly as low in terms of **cation exchange capacity**, although Au and Ha were on the boundary with the 'medium' class. The results are similar to exchangeable Mg in terms of farm differences: both models detected that Sh and Sa are significantly lower than Ha and Au (Tables 6-5 and 6-7). ♦ There were no short-term (Model 2) nor ♦ long-term (Model 1) cultivation effects, although in this last case, there is a suggestion of a decrease in CEC in the cultivated soils in respect to the controls for all farms except Ha (Figure 6-9).

Available P results are contradictory. ♦ Model 1 averaged across cultivated and controls and detected that Ha was significantly lower than Sh and Au, which were both significantly lower than Sa. ♦ Cultivation did not seem to be having an impact, as there were no significant differences between cultivated and control soils. Yet, Figure 6-10 strongly suggests that it is a high level of P in the cultivated soils, in respect to the controls, that explains the detected difference between Sa and the other three farmers, and possibly a lower level of P in Ha's cultivated in respect to the control, that results in the significant difference between this farm and the other three. ♦ This intuitive notion is supported in Table 6-2 where indeed Ha, Sh, Au and Sa's average cultivated and control values are rated according to MAFF (2000), as 3 and 4, 5 and 5, 5 and 5, 7 and 6, respectively. The cut-off levels between indexes are, of course, arbitrarily fixed, but along with Figure 6-10 they do increase the awareness that Model 1 may be inadequate because it averages across cultivated and control for all four farms, and does not seem to detect differences caused by cultivation that go in 'opposite' directions. Model 2, that only utilises time replicates in the cultivated soils, emphasises the problem raised by the conclusions of Model 1, as Sa is significantly higher than the other three farms, and Ha is significantly lower than the other three (Table 6-7). There are no short-term seasonal fluctuations (Table 6-7).

Available Fe is differentiated very clearly in terms of soil type but ♦ farming practices do not seem to have an impact on the levels (Table 6-5 and Figure 6-11). Au is significantly higher than the other four farms in the analysis, Sa is significantly lower than the other four, and Ab is significantly lower than Au, but significantly higher than the other three.

For **available Mn**, Ha is significantly lower than Au, Ab and Ha, and ♦ there is also a cultivation effect, as cultivated soils are significantly lower than the controls (Table 6-5). Figure 6-12 indicates that the extent to which this is correct depends on the farm, as it is almost insignificant for Au, but marked for Ha.

Available Zn has a significant 'Farm*Status' interaction term. At the level of the control soil, Sh was significantly different from Au, Sa and Ha but there was no difference between cultivated soils. With Sh, control levels were significantly lower than cultivated, while it was the opposite for Ha (Table 5-3). ♦ Figure 6-13 supports that cultivation is probably having an impact, but not in the same way for all farms.

Available Cu presents some very interesting findings. Here, too, the interaction term was significant. This meant that, at the level of the control soils, Sh and Sa were significantly lower than the other three farms but, at the level of the cultivated soils, Sa was actually lower than the other four. In the case of Sh and Ab, the control had significantly lower levels than the cultivated, an indication that cultivation is increasing levels of Cu in the farmed land (Table 6-5). If Figure 6-14 is examined, it is evident that cultivation is having no impact at all on Au, Ha and Sa, but is increasing levels for Ab and Sh, particularly for the latter.

In the case of **available Ni**, it is clear both from Table 6-5 and Figure 6-15 that ♦ cultivation is not having an impact on the farms, but there are differences between farms. Au is significantly higher than the other four farms, while Sa is significantly lower than Ab and Ha.

Available Cd has a significant 'Farm*Status' interaction term (Table 6-5). In the control soils, only Au was significantly higher than the other farms, while for the cultivated soils Ab actually had the highest levels (but was not significantly higher than Au, although it was in respect to the other three). For Ab and Sh, control soils were significantly lower in Cd than cultivated, but the opposite was true for Au and Ha.

In terms of **available Pb** the picture is quite simple. Sh is significantly higher than all other farms, while Au is significantly lower than all other farms, and ♦ there is no effect on cultivation (Table 6-4and Figure 6-17).

6.2.3.2 Relation to soil texture

So far, the soils have been grouped according to their chemical characteristics. The statistical analyses have provided much information on whether a particular chemical variable is determined primarily by intrinsic topsoil characteristics or influenced by cultivation practices. A further question remains, that is, are any variables linked to soil texture? The simplest way of gaining an understanding of this is to inspect Figures 6-2 to 6-17 (this analysis does not rely on any statistical tests). Figures 6-7, 6-8, 6-9, 6-11, 6-14 and 6-15 indicate the presence of strong groupings, which can probably be linked to texture.

In the case of CEC and exchangeable Mg (Figure 6-8 and 6-9), there is a definite suggestion that Sa and Sh can be considered as a group with lower levels, compared to Ha and Au. This is matched by the texture, as Table 6-1 shows that Sa and Sh are sandy loams and Ha and Au silt loams. The CEC of a soil is determined by the amount and the type of negative charge in the soil, and is usually a function of the amount and kind of clay, organic matter and soil pH, but in some horizons, silt can be a large contributor of CEC, and it is hypothesised that 15% silt in the 2-20μm range (fine silt) can account for as much as 10% of the CEC (Foth and Ellis, 1997). Therefore, the larger quantities of silt in Ha and Au are probably responsible for the larger CEC, and exchangeable Mg.

Similarly, there appears to be a link between texture and the amounts of exchangeable Ca (Figure 6-7), but this is weaker, as only Sh's levels are distinct from the other farms. Sa appears to belong to Ha and Au's group, but it has already been remarked that Sa experienced a significant and unexpected increase of Ca at T3, which would explain this finding.

Available Cu and Ni (Figure 6-14 and 6-15) also present marked groupings and it is speculated that in these soils texture is a strong controlling factor. For Cu at least, it is known that it can be present in the soil in many different forms. Significantly, it can be adsorbed on clay mineral surfaces—partly as exchangeable cations, or can be complexed with organic matter (Prasad and Power, 1997). For both metals, Ha and Au belong to a higher group (strikingly so in the case of Cu), Sh and Sa appear to belong to a lower group. In the case of Ni, Ab fits in appropriately (as it is a sandy loam) with Sh and Sa's group, but curiously in terms of Cu it is grouped with Ha and Au. It is postulated that as this site has a long history of fertilisation with refuse ash, and as the control samples may have been affected by ash drift, the discrepancy caused by Ab's Cu results may be the outcome of cultivation practices. Likewise, the markedly higher Cu value for Sh's cultivated soil in respect to his control does not contradict the idea that Sh and Sa belong to a lower Cu group, as it may be the result of particular cultivation practices.

Iron presents strong groupings and marked overlap between control and cultivated soils for each farm, which suggests that some characteristic of the soil type overrides any effects of cultivation, but it is not likely to be soil texture (because unlike the other variables, there does not seem to be any correspondence between texture and Fe levels). Controlling factors of Fe availability include soil pH, organic matter and the amounts of other nutrients such as P, Cu, Zn and Mo (Prasad and Power, 1997). The remaining variables do not seem to be related in any way to texture. Exchangeable Na and K that could perhaps be linked to texture because they are adsorbed onto the cation exchange complex, do not show any strong groupings.

6.2.3.3 Farmers' classification of soil

It was very difficult to gain an understanding of the way in which the farmers classified their soils. A comparison of the farmers' groupings and the groups in Table 6-1 suggests that texture and colour are important variables (as there was a certain degree of correspondence between systems) but not the only ones, because Ab's land was perceived as different in respect to Sa and Sh, even if texturally they were similar. Formal interviews with the farmers were unproductive, as most claimed to know very little about different soil types, and although they were able to distinguish between the soil types on their own land and their closest neighbours, their knowledge did not seem to extend further afield. Of course, they did have criteria to distinguish between soils but somehow they did not seem to articulate this formally. They would occasionally mention that a '*black soil is better than a red soil*' or '*this soil does not need ash because it gets laka (clay) from the river which makes it soft*' or perhaps '*my land needs to be irrigated once every two days, Abdullahi's land only requires it once a week*'. The criteria that emerged more frequently were texture, colour, frequency of irrigation (farmers made clear that this was controlled by soil texture), and type of crops that could be grown on a particular location.

Only one farmer (sixty to seventy years old, with plenty of farming experience, who farmed a large portion of land) proved to be well informed as he described eight different soil types (Table 6-8), but cautioned that there were many more in other States. He explained that his knowledge and that of other farmers on soil types and crops was localised, it depended on the types of soils they were exposed to and which crops they chose to grow. The words he used to classify soils tended to be physical as he used words meaning hard/soft, thick/fine, clay/sand, and concepts of colour and water retention. There did appear to be a slightly utilitarian dimension to his classification, as he thought of some soils in terms of whether they were suitable for farming, regardless of their other properties. For example, he described *palista* as 'not clay, not sand, soft', and *rairai* as "*very soft, very fine, it would appear to be useless for agriculture but, in fact, it is suitable, it is found in Lafiya, Kano and Gigawa States*". These findings are similar to those of some research work in northern Zambia, where the farmers' system of categorising soils is oriented towards practice and is relative and site-specific rather than absolute and universal (Sikana, 1994). Phillips-Howard and Kidd (1991) who conducted interviews in the Delimi Langalanga area also found that soils were distinguished by colour, water-holding characteristics, irrigation requirement, softness, and suitability for crop growth. They also revealed that farmers linked certain physical characteristics to fertiliser requirement (for example '*a black soil needs less fertiliser than a red soil*' and a '*hard soil needs more fertiliser than a soft soil*'), but they came to the critical conclusion that *in terms of utility* farmers considered all soils to be the same, because they were confident that with sufficient time and good husbandry they could render any soil type suitable for cultivation. It is curious that this idea was never expressed during the 2000/2001 fieldwork period, and indeed the key informant described a *shabua* soil as 'any land that is not very good, crops will grow to a certain point and then deteriorate', indicating that he recognised the existence of soil types that were unsuitable for farming.

Nothing more can be said about soil classification at this stage. Farmers seemed unable and/or reluctant to attempt a soil classification and so this avenue of enquiry was abandoned. Future research should perhaps investigate whether the apparent lack of 'knowledge' is an effective lack of knowledge (caused by lack of experience/heavily localised experience or disinterest towards classification because, as Phillips-Howard and Kidd (1991) concluded, farmers believed that any soil type could be managed by good husbandry), or an inability of most farmers to formally express concepts of soil classification.

Table 6-8: Local soil classification provided by one key informant

Soil name	***Physical properties***	***Suitability for farming***
Kasan ki	Reddish soil.	Not very good for farming.
Laka	Clay, heavy soil, cannot easily cut into it while farming.	Not good for carrot.
Palista	Not clay, not sand. It is soft.	-
Tabo	Thick, heavier than laka. It is hard to break until you pound it. It is medium brown.	-
Rairai	Very soft, very fine. You find it in Lafiya, Gigawa, Kano States.	It is very useful for agriculture, even though you would not think so.
Jan gargari	Clay for making pots. It breaks very easily and there is sand in it.	-
Bakwa	It retains water but when it dries it cracks a lot.	-
Shabua	-	Any land that is not very good. Crops will grow to a certain point and then deteriorate.

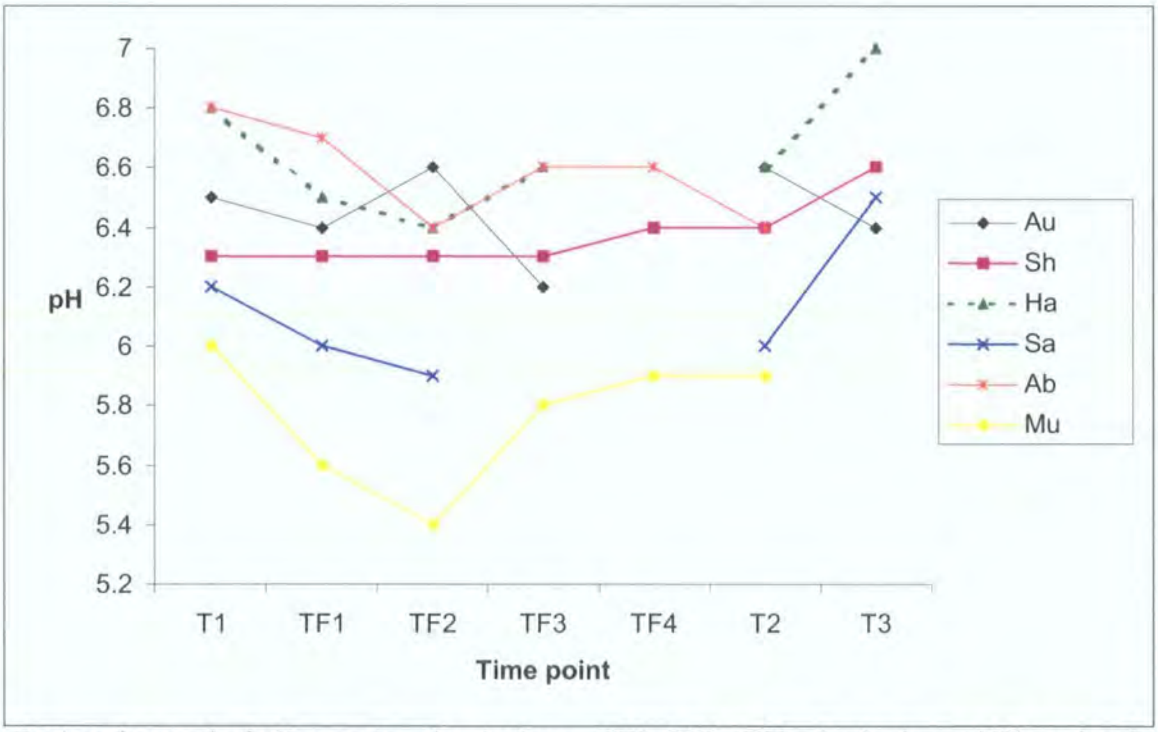
6.2.4 Seasonal pH fluctuations

The pH results require a separate discussion because, unlike the other variables, pH was actually tested on every sample collected during the fieldwork (4.2.6). Thus, as well as having data on the time points referred to as T1, T2 and T3, there are additional time points between T1 and T2, taken one week after each fertilisation round. This thorough analysis was carried out because the primary mode of action of ash is thought to consist in neutralising soil acidity (because of the high pH), which would make nutrients more available (Phillips-Howard and Kidd, 1991).

6.2.4.1 Data

As discussed in section 4.5.2, pH was analysed with a 'single factor within subjects design'. Tukey's multiple comparisons pinpointed the time points that differed significantly from any others for each individual farm (Table 6-9). Figure 6-18 allows the visualisation of the trends over the season although it does not provide an indication as to which time points differ significantly. In any case, it becomes apparent that each farm is exhibiting different patterns.

Figure 6-18: Variation of mean pH values over the farming season for each farm



Depicts the trend of pH over time for six farms. 'T1', 'T2', 'T3' = beginning, middle and end of the farming season, respectively. The time points variously labelled 'TF' represents the samples taken one week after fertiliser application (inorganic or organic) and the farms differed in their number of applications (e.g. Sa applied fertiliser twice, Sh four times). Farms were also fertilised between the 'T2' and 'T3' time points, but no samples were collected for this stage.

Table 6-9:Outcome of a single-factor within subjects anova on pH for all farms

Farm	*F value*	*p value*	*Mean pH value for each time point*	*Tukey's HSD test*
Au	2.19 (5,45)	N.S.	T1=6.5 start T_{F1}=6.4 T_{F2}=6.6 T_{F3}=6.2 T2=6.6 middle T3=6.4 end	-
Ha	17.94 (5,45)	<0.001	T1=6.8 start T_{F1}=6.5 T_{F2}=6.4 T_{F3}=6.6 T2=6.6 middle T3=7.0 end	T1>T_{F1} & T_{F2}, T3>T1,T_{F1},T_{F2},T_{F3} & T2
Sa	10.20 (4,36)	<0.001	T1=6.2 start T_{F1}=6.2 T_{F2}=5.9 T2=6.0 middle T3=6.5 end	T3>T_{F1}, T_{F2} & T2
Sh	5.32 (6.54)	<0.001	T1=6.3 start T_{F1}=6.3 T_{F2}=6.3 T_{F3}=6.3 T_{F4}=6.4 T2=6.4 middle T3=6.6 end	T3>T1,T_{F1},T_{F2},T_{F3} & T_{F4}
Ab	8.35 (5,45)	<0.001	T1=6.8 start T_{F1}=6.7 T_{F2}=6.4 T_{F3}=6.6 T_{F4}=6.6 T2=6.4 middle	T1 & T_{F1}>T_{F2} & T2 T_{F2}<T_{F3}
Mu	10.23 (5,45)	<0.001	T1=6.0 start T_{F1}=5.6 T_{F2}=5.4 T_{F3}=5.8 T_{F4}=5.9 T2=5.9 middle	T1>T_{F1} & T_{F2} T_{F1}<T2 T_{F2}<T_{F3},T_{F4} & T2

Degrees of freedom are in brackets. The fourth column lists the mean pH values for each time point (the beginning, middle and end of season time points are marked appropriately and the time points corresponding to one week after a particular fertilisation round are marked with a subscripted 'F' followed by a number), and the last column indicates which of these means were significantly higher (>) or lower (<) (according to Tukey's HSD test).

6.2.4.2 Discussion

It is apparent from Table 6-9 and Figure 6-18 that the pH fluctuates quite dramatically over the course of the season, and that there are significant differences between time points. Quite frequently, T3 tends to be significantly higher than the other time points, and Figure 6-18 suggests that there is a tendency for pH values to drop in the course of the season, but return to values equal to or higher than the starting point. The pH fluctuations are, perhaps, unsurprising as this parameter varies seasonally in the soil (James and Wells, 1990), at least in temperate climates. It is highly sensitive to a range of factors. Prasad and Power (1997) list these relevant factors: 1) Application of chemical fertilisers; 2) Removal of basic cations; 3) Leaching of bases. In Nigeria, there is an additional factor, as the Harmattan dust is a considerable source of basic cations (Harris, 1998).

Several authors have researched the extent of the Harmattan dust deposition, and its chemical composition, in different countries (e.g. Tiessen *et al.*, 1991; Møberg *et al.*, 1991). Research carried out in Northern Nigeria (Møberg *et al.*, 1991) showed that the average amount of dust deposited from November to mid March was 580 kg ha^{-1}. Using their results, the authors estimated that in the Kano-Kaduwa-Zaria area the total dustfall for the dry season was likely to be in the range of 700-1000 kg ha^{-1}. The dust was dominated by fine silt (42%) and contained significant amounts of clay (36%). It had a pH of 7.0, high organic carbon content (4%), and high extractable phosphorus content (87.0 mg kg^{-1}). Cation exchange capacity was 36.2 $cmol_{(c)}$ kg^{-1} and, on average, exchangeable Ca, Mg, K and Na values were 23.8, 4.39, 3.74 and 3.32 $cmol_{(c)}$ kg^{-1}, respectively. When the average properties of farmed soils in the Delimi area (see first paragraph in 6.1) are examined, it is evident that base saturation of these soils is high. The Harmattan dust is likely to be responsible for this high base saturation (a study in northern Ghana came to similar conclusions—see Tiessen *et al.*, 1991), and indeed, if a deposition rate of 700 kg ha^{-1} is assumed for the Jos Plateau (as the dry season here is shorter in respect to the Kano area), then the dust will contribute 3.33, 0.37, 1.02, 0.53 kg ha^{-1} $yr^{-1}$of Ca, Mg, K and Na, respectively.

An attempt at linking the pH fluctuations to farming practices was made by examining Figure 6-18 and Table 6-11. Table 6-11summarises the number of fertiliser applications throughout the farming season for each farm, identifying the type, or the particular combination of types at each round. Unfortunately, this analysis did not yield any interesting results as the pH fluctuations appear unconnected to fertiliser type.

It is likely that the fluctuations are the sum of different factors (that have different weightings in each farm), such as the impact of growing crops, leaching, fertiliser application, quality of irrigation water, etc. The observed general increase in soil pH during the season does not seem to be a direct result of the ash application, despite the high pH and base cation content of the ash, although of course it is possible that there was a time-lag effect. A plausible explanation for the rise in pH by the end of the season is that it could be linked to the quality of irrigation water. With the progress of the dry season the flow of the Delimi river is reduced so that the concentration of nutrients and pollutants increases. Indeed, the semi-quantitative data in Table 6-18 indicates that there are large amounts of base cations relative to other dissolved metals in two samples of Delimi river water. The increased concentration may counteract the leaching of nutrients caused by the process of irrigation and the uptake by plants, and this could result in the effective increase of basic cations and, hence, a rise in pH (Alexander, Pers. Comm.).

In summary, although no connection can be made between pH and fertiliser application, the fluctuations (that can be very dramatic) stress the difficulty in commenting on the statistical analyses in Table 6-4. If only one time point is used in comparing cultivated soils to control soils, it obscures the fact that pH in the cultivated soils fluctuates as a result of management practices. Yet, using an average of all the time points would also be unsatisfactory.

6.3 LINKING SOIL NUTRIENT LEVELS TO FERTILISATION PRACTICES

This section complements the analysis of the sustainability of the case study farms because it links the changes in nutrient levels to farming practices. The first subsection reviews some of the practical issues linked to measuring fertiliser inputs over the course of the season. The second subsection presents the data relative to the amounts of IF and organic fertiliser applied by the six case study farmers, whilst the final subsection discusses the most significant soil data results, connects them, where possible, to farming practices, and provides an analysis of whether farmers appear to be meeting the crops' seasonal nutrient demands.

6.3.1 Procedure

Each farm was monitored throughout the farming period to keep a record of fertiliser applications (4.2.8 and 4.2.9). Where possible, the IF was measured directly with a bucket and spring balance but at other times, it was necessary to rely on the farmer's estimate in local units (see 4.2.8). Ha, Sa and Sh's farms were the ones where direct measurements were made most frequently. Au's farm was the most difficult to follow because the land was tended by hired labour who changed frequently and did not always warn when they were planning to fertilise. A second difficulty was that Au's farm consisted of more than one embankment and sometimes the whole land was fertilised (so the IF estimate included land that was not part of the study area), and at other times just covered the relevant portion. There were never any direct measurements for Ab and Mu, only estimates in *mudus*. The estimate for the whole season can be derived by doubling the measurement for half a season, on the assumption that the total amounts would not change considerably in the second half of the season (although it is possible that the *type* could have changed).

The measurement of ash was slightly more complicated, for all the reasons given in 4.2.9. Therefore, the weights of ash given below in Table 6-10, were for the most part estimates, not direct measurements. They were obtained in the following ways:

1. Ha's ash was measured directly with a bucket and spring balance. He partly filled two empty 50kg fertiliser bags: one weighed 37kg, the other 25kg so, in total, 62kg were applied.
2. Sh applied ash twice but only one application was measured directly (43kg). He applied ash a second time and guessed that he put about 12 sacks, but given the size of the land this

seems unlikely. It is probable that he applied the same amount as the first time (this was used in Table 6-10).

3. For Ab, it was possible to weigh one bag of ash (ash is put into empty fertiliser bags to facilitate application- the bags are generally filled halfway). It weighed 35.7kg, so the total amount was calculated by multiplying this amount by eight bags.
4. Mu applied one 50kg sack of ash, which was nearly full. The weight was estimated at 40kg.
5. Au applied 4 bags to his land. An estimated weight was calculated by multiplying the number of bags by a mean estimated value of 32kg per bag (obtained from the other farmers' sack weights).

6.3.2 Data

Table 6-10 provides information for each of the six farms on: area of the land under study; total weight of IF applied; weight of every individual type of IF (in the case of mixtures it was calculated by taking into account the total amount of IF applied, and the relative proportions of each type); amount of IF applied per square metre of land (calculated as total amount/area of land); estimated weight of ash applied; amount of ash applied per square metre of land.

Table 6-10: Fertiliser application for six farms in the study site

	Au*	***Ha***	***Sa***	***Sh***	***Ab***	***La***
Farm area	1000/*1386m²*	222m²	439m²	242m²	796m²	188m²
Total IF application	39/*90kg*	17.05kg	63.91kg	51.25kg	54.8kg (half season)	16.55kg (half season)
Individual IF	Golden-25kg NPK15:15:15-5.9kg Urea-3.4kg Superphosph.-4.6kg Golden-30kg NPK15:15:15-60kg	Golden-0.27kg Kampa-4kg NPK15:15:15-9.09kg Urea-3.59kg	Golden-3.4kg Kampa-15.07kg NPK15:15:15-26.6kg Urea-13.92kg Superphosph.-15.07kg	Golden-3.8kg Kampa-14kg NPK15:15:15-33.45kg	NPK 15:15:15-54.8kg (half season)	Golden-5.7kg NPK 15:15:15-3.8kg Urea-4.8kg Superphosph-2.25kg (half season)
Amount IF /Area	102g m⁻² (full season)	77g m⁻² (full season)	145g m⁻² (full season)	211g m⁻² (full season)	136g m⁻² (estimate-full season) *68g m⁻² (direct-half season)*	174g m⁻² (estimate-full season) *87g m⁻² (direct-half season)*
Ash†	4 bags≅128kg	62kg	-	2 applications ≅86kg	8bags≅286kg	1 bag≅40kg
Amount Ash /Area	128g m⁻²	280gm⁻²	-	355g m⁻²	359g m⁻²	212g m⁻²

Fertiliser measurements for Ab and Mu only refer to half a season, so the full season amount of IF per unit area is obtained by doubling the direct measurement for half a season. *Au presents two estimates of farm area and total IF application because they are both required for the calculation of the amount/area figure. Au's IF estimates sometimes referred only to the portion of land of interest (size and IF application are in normal type) and sometimes to portion of interest plus two lower terraces (size and IF application in italics). So the calculation of the amount/area is given by the equation $=(39{,}000g/999.93m^2)+(90{,}000g/1386.27m^2)$. † The weight of a bag of ash differed between farmers; see text for details on how these estimates were calculated.

6.3.3 Discussion

Sections 6.1 and 6.2 have characterised the nutrient status of each study farm, providing an indication of whether the nutrient levels are primarily influenced by cultivation practices or intrinsic soil characteristics. A third step in defining if the agricultural practices on each farm are sustainable consists in fully understanding the impact of past cultivation practices, and judging whether fertiliser application is likely to be meeting crop demand.

The statistical tools employed in the research project (6.2) were imperfect, as one looked for differences between farms averaging across cultivated and control (Model 1), and the other looked for differences between farms averaging across time points *only* for the cultivated soils (Model 2). Some discrepancies were inevitable. Nevertheless, the two models *did* provide fairly consistent outcomes and some interesting findings. Unsurprisingly, cultivation has modified the nutrient status of the soils. Briefly, the most noteworthy findings are that organic C, total N, exchangeable K, exchangeable Mg and available Mn have decreased in the cultivated soils in comparison to the controls. Although it is not statistically significant, there is a suggestion for a similar trend for CEC. The consequences of cultivation on pH, available P, Zn, Cu and Cd seem to vary amongst farms, whilst exchangeable Ca, available Fe, available Ni and available Pb do not seem to be affected by cultivation in any way.

Organic C is usually taken as an indicator of the amount of organic matter in the soil. Organic matter, which originates for the most part from plant tissue, is a primary source of native nutrients of a soil (the dry matter is made up primarily of C and O, a smaller amount of H, and very small amounts of S, N, P, K, Ca, Mg and trace elements) (Prasad and Power, 1997). Over time, it tends to decrease in cultivated soils because cultivation increases the rate of oxidation, and the removal of the harvest reduces the input of organic matter. This can lead to reduced soil stability; increased soil sensitivity to erosion; a reduction in microbial biomass and a consequent decrease in the amounts of nutrients mineralised each year, particularly N, P and S; and a decline in the CEC which reduces the soil's ability to hold nutrient cations against leaching (Rowell, 1994). This can have extremely negative consequences for light-textured soils whose CEC is primarily associated with organic matter, or in soils where kaolinite clay dominates (this is the case for the soils on the Jos Plateau—Hill and Rackham, 1973): in these cases, as the organic matter decomposes rapidly, the soil's ability to hold nutrient cations decreases, leaching losses are large and the soil becomes susceptible to erosion (Rowell, 1994). The lower levels of organic C in the cultivated soils in the study area in respect to the controls are, therefore, a result of cultivation. Although farmers apply ash in combination with IF, the quantities of organic matter contained in the ash are not sufficient to counteract the effects of cultivation. The decline in N, exchangeable K and Mg, available Mn and the perceived (but not statistically significant) decline in CEC also are most likely associated to a decline in organic matter, although the decline of K, Mg and Mn could also be attributable to crop uptake.

For the most part, Model 1 detected general effects of cultivation that were common to all farms, but some were farm-specific. These could probably be linked to specialised farming practices but as information on past activities is difficult to acquire, conclusions are speculative. Farmers do not keep records of what exactly they apply, and in what quantities, and when they deviate significantly from their 'plan', they may not remember the details over the years. In one farming season alone, they may need to alter their strategy quite significantly owing to changes in fertiliser availability. Table 6-11 summarises the actual fertiliser combinations used in the 2000/2001 season, and this can be compared to their expressed intentions during the interviews. Frequently, they did not correspond.

Au expressed the intention of only using Golden (a particular brand of NPK15:15:15) and ash on the particular study site, although he would mix Golden and urea on the other land he owned. In reality, although he mostly applied NPK15:15:15, it was not always Golden, as he intended. Ha explained that he preferred mixing Golden and urea but if he was inter-cropping carrots and lettuce, once the lettuce was harvested he would apply some super-phosphate. On the land under study, he planted lettuce and spinach in the first half of the season, and lettuce and beetroot in the second half. Ha followed his plan in the first half of the season but dropped the application of urea in the second half. Sa's strategy was to apply a mixture of IFs in the ratio of two bags of NPK15:15:15, one bag of urea and one bag of super-phosphate. On some portions of land he also applied ash, but he believed that the particular portion of land under study did not require it because it was sufficiently 'soft'. For the most part, Sa was consistent in what he intended to apply and what he effectively applied. Sh planned to use Golden and urea, or super-phosphate and urea, and ash if he could obtain it, but he was the least consistent, as he used different brands of NPK15:15:15 (but very little Golden), and never purchased urea. Ab stated that ideally he would combine urea, NPK, super-phosphate, Golden NPK, ash, and egret, chicken, sheep and goat manure because they all have separate roles, but as he could not obtain them all he would apply super-phosphate at the beginning of the season, and perhaps some ash, and continue with NPK and ash applications. He cautioned that availability would determine what actually happened and, in fact, Ab was not very consistent as he only applied NPK and ash. Mu planned to use NPK15:15:15, followed by Golden NPK, or possibly urea, ash, and finally Golden, and although he generally followed his strategy, he had not expressed the intention of mixing during his interview.

This illustrates how difficult it is to obtain clear information on past practices, when even one season's plan can undergo considerable changes. Similarly, it is difficult to ascertain the extent and type of ash used by the farmers over the course of the years. All farmers, except Sa, claimed to have used ash in their fertility strategy but they differed in the degree to which they relied upon it. Ab probably has a definite history of using town refuse ash because his farm is easily accessed by tipper trucks from the roads, and in the study season he produced his own from the refuse that had been strewn across his low-lying land during the floods. Sh also claimed to have regularly used town refuse ash in previous years, but less often now because it had become increasingly difficult to obtain. During the study period he did apply ash but he produced it by burning farm residues. Au used farm ash that season but claimed he had used town refuse ash in the past, while Ha explained that he mainly produced farm ash, although occasionally he would use town refuse ash.

Table 6-11: Combinations of fertiliser applied to six farms during the first half of the farming season

	TF1	*TF2*	*TF3*	*TF4*	*TF5*	*TF6*	*TF7*
Au	NPK	NPK	NPK+urea+ superphosphate+ash	-	NPK	NPK	-
Ha	NPK+urea	Kampa(NPK) +urea	Ash	-	NPK	NPK	-
Sa	NPK+urea+ super-phosphate	Kampa+urea+ super-phosphate	-	-	NPK+super-phosphate	NPK+urea	-
Sh	NPK	Ash	NPK	Ash	Kampa	NPK	NPK
Ab	NPK	Ash	Ash	NPK	n.r.	n.r.	n.r.
Mu	NPK+urea	NPK	Urea+superphosphate	Ash	n.r.	n.r.	n.r

Fertiliser applications at different time points for six farms. TF1 to TF4 fall within the first half of the cropping season, TF5-TF7 fall within the second half (n.r. = not recorded). A dash indicates that a farmer stopped fertilising in that particular half of the season.

Available P constitutes a special case. Although Model 1 did not identify any statistically significant differences between cultivated and control levels of available P in any of the farms, Figure 6-10 suggests that there is a difference, even if not significant, in Sa's farm and maybe Ha's. This is supported by the ratings according to MAFF (Table 6-2), so this represents a situation where there are no statistically significant differences between two locations, but there are agriculturally important differences. It is essential to recognise this, as usually MAFF recommendations will be based on the average P value for a farm, regardless of the variability across the field. For Sa, there is a marked increase in the cultivated in respect to the control, and this is most certainly the consequence of IF application. Table 6-10 lists the types and total amounts of fertilisers applied during the farming season by the four farmers in the study, and Table 6-11 illustrates in what combinations. Although Sa favoured forms of NPK15:15:15, he mixed in substantial quantities of super-phosphate (and urea), unlike the other three farmers. The information provided in the previous paragraph would suggest that Sa has been quite consistent in adopting this strategy over the course of the years and, evidently, he is building up the reserves of P in his farm through the application of super-phosphate. In contrast, Ha does not integrate super-phosphate in his management strategy, unless he is planting carrots, and thus he appears to be experiencing a decline in available P levels, although there is strong overlap between the cultivated and the control soils. His cultivated and control soils are ranked as index 3 and 4 by MAFF, which suggests that he needs to apply super-phosphate to build up the soil's P reserves. Sh and Au seem to be maintaining P levels in a satisfactory manner, and an index of 5 indicates that there is no requirement for P fertiliser at present, because of the large soil reserves. It is intriguing that Au should not be experiencing a P decline, and yet claims to only use NPK15:15:15. His land is adjacent to Ha's, both soils are silt loams, both farmers appear to have a similar soil fertility management strategies and still, Au is satisfactorily maintaining P levels at index 5, while Ha is considerably lower at index 3.

Available Zn is difficult to interpret because there is no consistent effect of cultivation across farms. Sh's cultivated levels are significantly higher than his controls, and it is the opposite for Ha. Why this should occur is open to speculation: Zn is a minor plant nutrient, and perhaps the crop types grown on Ha's land, over the years, have taken up significant quantities of Zn that have not been replaced through fertilisers. Sh seems to have had a history of using large quantities of ash, that could have led to the enrichment of Zn in the soil over the years. If available Cu and Cd levels are examined, this theory seems sound, as the cultivated levels are higher than the controls, particularly for Cu. Ab, too, seems to be experiencing an increase in Cu and Cd levels (the latter more so than the former) in his cultivated soils in respect to the controls, and this would be consistent with his claim of using large quantities of ash over the years. Inexplicably, Au and Ha's Cd was higher in the controls than the cultivated. The pH is a variable that shows inconsistent patterns between cultivated and control as, in the case of Au and Mu, cultivation has resulted in an increase. In Sa's case, it seems to have resulted in a decrease, and it does not seem to have affected the remaining farms. However, it is difficult to draw any conclusions from this, because the data presented in 6.2.4 has shown that it is problematic to make a static comparison between T2 and the control, because of the wide seasonal fluctuations in the cultivated soils.

To some point, the finding that Sh and Ab's farms are enriched with certain heavy metals (Zn, Cu, Cd) is likely to be the consequence of the past (and present, in Ab's case) use of town refuse ash. Intriguingly, the high levels of Ca would not appear to be tied to ash applications (despite the very large quantities of Ca in ash—see Table 7-1), as there was no significant difference between cultivated and control soils. It could be postulated that the method for spreading the ash is such that some drifts onto the control areas so that all the area is enriched, but this raises the question as to why there should be detectable differences between control and cultivated soils in other element levels.

A point which requires some consideration is whether the IF applications recorded during the farming season were sufficient and adequate to meet the crops' demands in each farm. Taking into consideration the amounts contained in NPK15:15:15, and that urea consists of 46% N, and triple super-phosphate contains 47% P_2O_5 (MAFF, 2000), the quantities recorded in Table 6-10 could be converted to nutrient amounts applied per hectare (N.B. Calculations were not straightforward because the amounts recorded sometimes referred to the portion of land under study, sometimes to larger portions of land). These estimates are listed in Table 6-12, along with information on the P and K soil indexes and the two crops planted during the farming season.

Table 6-12: Estimated nutrient inputs (kg ha^{-1}), soil status and crops grown on four farms

	Au	*Ha*	*Sa*	*Sh*
N fertiliser	158.3	164	299	318
P fertiliser	164.6	90.3	315	318
K fertiliser	143.3	90.3	154	318
P index	5	3	7	5
K index	3	3	3	2
1st Crop	Lettuce	Lettuce/spinach on ridges	Lettuce	Lettuce
2nd Crop	Lettuce	Lettuce/beetroot	Carrots	Lettuce

It must also be remembered that the farmers complemented their IF applications by spreading ash onto the immature crops and soils. This application will supplement the crops' needs with macro and micro-nutrients, but the estimation of the contribution of nutrients by ash is uncertain for several reasons. Firstly, it was not feasible to make direct weight measurements (for the reasons detailed in 4.2.9) so, in most cases, the amounts recorded in Table 6-10 are approximate. Secondly, the farmers had little ash so few replicates could be collected from them for nutrient analysis. Thirdly, as the laboratory analyses revealed, the variability of ash is considerable, even in an apparently 'homogeneous' batch, so using the mean may not reflect the actual amounts of nutrients added (section 7.1). Fourthly, the percentage of elements in the ash that is in plant available form is not known, and the 'total' amounts measured do not provide any indication. And fifthly, when ash is applied during crop growth, some of the ash falls to the soil but most falls on the crop leaves, and this raises the question of how much it can contribute to crop nutrition via foliar fertilisation. All these factors need to be considered when examining the potential contribution of *total* elements in Ha and Sh's farms in Table 6-13. No determination was possible in Au's case because no ash samples could be collected for his farm. Ab and Mu have been included in Table 6-13 to provide further information on the potential contribution of nutrients by ash, but as they are lacking soil data, no further analysis can be done for them. The most apparent feature of Table 6-13 is that there are differences in the amounts received by each farm. The dominant elements in all applications are Ca, Fe, K, Mg and Na, approximately in that order. In some cases, the amounts involved are considerable, so even if they were mainly in plant-unavailable forms, they could still provide a noticeable contribution to the soil. The other elements are relatively minor, although there can be marked differences between farms (e.g. Cu, Zn, Pb). Aw and La are receiving the largest amounts of Na, K, Ca, Mg and Zn, while Ab's ash is contributing larger amounts of Fe, Cu, Ni, Cd and Pb than the other farms. Phosphorus was determined in its available form, and although there are differences between farms, the figures are insignificant when compared to the application of IF.

Table 6-13: Estimated element contribution to four farms through ash application ($kg\ ha^{-1}$)

Element	*Ha*	*Sh*	*Ab*	*Mu*
Avail. P	0.11	0.29	0.04	0.10
Na	24.36	8.45	6.86	15.36
K	46.91	31.18	8.33	35.98
Ca	372.43	54.82	27.69	343.51
Mg	23.50	8.09	1.70	19.49
Fe	56.94	61.98	98.93	39.62
Mn	1.16	1.23	0.82	0.81
Zn	5.49	0.60	1.75	2.29
Cu	0.53	0.11	1.28	0.29
Ni	0.08	0.06	0.09	0.05
Cd	0.027	0.02	0.04	0.02
Pb	0.85	0.17	1.32	0.43

Figures are estimated using data from Table 6-10 and the nutrient characteristics of ash samples specific to each farm (Ha = two town ash samples; Sh = three wood/leaf ash samples; Ab = ten river ash samples; Mu = one town ash sample).

The information contained in Table 6-12 can be coupled with MAFF (2000) guidelines for crop fertiliser requirements. This analysis reveals that Au, Sa and Sh's P soil indexes were sufficiently high so that no additional P fertiliser would have been needed for the crops they planted. Ha's situation is a little more complicated because he practised intercropping but, in any case, with his soil index a single lettuce crop would require 100kg ha^{-1} of P and a single beetroot crop would require 50kg ha^{-1} of P, so it is obvious from Table 6-12 that he is not applying sufficient P fertiliser. Au's K soil index is sufficiently high so that no potash is necessary, while Sh's soil index indicates the need for K fertiliser, which he is adequately meeting. Sa's carrot crop would require 35kg ha^{-1} of potash and he is more than meeting this need, whereas a single beetroot crop would need 60kg ha^{-1} potash, and, therefore, Ha is also probably meeting the crop's requirements.

To summarise, this analysis indicates that farmers Au, Sa and Sh met the season crops' P and K demands and, in fact, they probably over-applied IF. It must be remembered though, that the analysis of the soil data presents evidence for a slow decline in K soil levels in cultivated soils in respect to the controls, and that in Sa's farm there is P enrichment, while Au and Sh are maintaining soil levels. It is possible that farmers have not always been able to meet crop demand over the course of the years. Ha's case gives rise to concern as his IF applications seem to be less than adequate, and the soil data point to P mining. How fast this will occur is unknown because his P applications may vary over the course of the years. Ash will contribute some P but probably not enough (0.11kg ha^{-1}, presuming it is completely deposited in the soil). Ash, though, may provide reasonable amounts of secondary nutrients, such as Ca, K and Mg (through deposition on the soil or foliar fertilisation) to all farms except Sa's (who is not applying ash).

6.4 HEAVY METAL ACCUMULATION IN THE FOOD CHAIN

This section concludes the analysis of the sustainability of the case study farms, as it addresses objective V. The study farms cannot be considered sustainable, even if they are meeting crop nutrient demands without mining the soil if SFM practices are resulting in the accumulation of heavy metals in the soil and crops. Section 6.1 and 6.2 have already provided information on whether the soil appears to be accumulating heavy metals. Overall, the levels of all heavy metals fall within the typical range for soils, except for Sh's Pb levels. However, there is some indication of Zn, Cu and Cd enrichment in Sh and Ah's farms, probably as a result of ash application. This, though, does not necessarily presuppose crop uptake. The only way to determine this is to test the crop samples for heavy metals, and then link these results to soil levels.

6.4.1 Procedure

Section 4.2.10.3 describes the sampling procedure for the crops. In all, six crop batches (four lettuce, one carrot and one cabbage batch) were tested for heavy metals, and compared with a one-way anova (4.5.4). The relationship between soil extractable metals and total crop concentrations was investigated by plotting the mean soil concentration for each farm against the mean crop concentration (for lettuce and carrot batches) for each variable. This was not a formal regression analysis but it was carried out simply to form an impression of the possible relationship between soil and crop concentrations (4.5.4).

6.4.2 Data

Table 6-14 presents the mean values and standard deviations for total concentration of Fe, Mn, Zn, Cu, Ni, Cd and Pb in every batch tested. Four batches consisted of lettuce (batches labelled Ab, Au_{LE}, Ha, Sh), one batch of carrot (Sa's farm) and one batch of cabbage (Au_{CA}, obtained from a section of Au's farm which was not under study). All batches consisted of ten replicates except for Sa and Au_{CA}, where one sample was lost during preparation, and Au_{LE} where one sample was excluded from the analysis because it appeared to have been contaminated (probably by soil). The batches were compared using one-way analysis of variance and a significant result was followed up with Tukey's Honestly Significant Difference Test to establish which means differed significantly from the others. Table 6-15 shows that there are significant differences between batches for all variables.

The plots of soil DTPA extractable levels of Fe, Mn, Zn, Cu, Ni, Cd and Pb against the crop concentrations are displayed in Figure 6-19 to Figure 6-25.

Table 6-14: Mean values and standard deviations (in brackets) of different variables in six different crop batches (10 replicates each - mg kg^{-1})

Variable	*Au_{LE} lettuce*	*Ha lettuce*	*Sh lettuce*	*Ab lettuce*	*Au_{CA} cabbage*	*Sa carrots*
Tot. Fe	1585 (422)	1840 (1265)	2290 (537)	2417 (1092)	1139 (989)	118 (30)
Tot. Mn	40.26 (6.58)	50.26 (21.57)	56.59 (13.29)	50.62 (11.93)	17.87 (8.52)	11.39 (4.20)
Tot. Zn	57.56 (8.21)	66.48 (23.65)	182.1 (123.9)	85.65 (11.65)	70.81 (23.3)	53.67 (17.55)
Tot. Cu	8.63 (0.90)	13.92 (5.44)	5.58 (0.80)	8.98 (1.09)	2.84 (0.90)	4.40 (0.98)
Tot. Ni	2.57 (0.41)	2.97 (1.82)	3.47 (0.91)	3.63 (1.58)	1.72 (1.25)	1.21 (0.83)
Tot. Cd	0.28 (0.07)	0.32 (0.06)	0.21 (0.03)	0.15 (0.03)	0.07 (0.03)	0.72 (0.30)
Tot. Pb	5.88 (1.44)	11.58 (2.88)	9.85 (3.86)	10.84 (3.90)	8.58 (7.54)	6.07 (2.64)

Table 6-15: Outcome of a single-factor within subjects analysis of variance for different variables measured in six crop batches

Variable	*F value*	*p value*	*Tukey's HSD test*
Tot. Fe	9.30 (5,51)	<0.001	Sa<Au_{LE}, Ha, Sh, Ab Au_{CA}<Ab
Tot. Mn	20.84 (5,51)	<0.001	Sa<Au_{LE}, Ha, Sh, Ab Au_{CA}<Au_{LE}, Ha, Sh, Ab
Tot. Zn	7.72 (5,51)	<0.001	Ha, Al_{LE}, Aw, Al_{CA}, Ah<Sh
Tot. Cu	25.68 (5,51)	<0.001	Au_{CA}, Sa<Au_{LE}, Ab, Ha Sh<Ab, Ha
Tot. Ni	5.51 (5,51)	<0.001	Sa, Au_{CA}<Sh, Ab Sa<Ha
Tot. Cd	29.62 (5,51)	<0.001	Au_{CA}<Au_{LE}, Ha, Sa Au_{CA}, Ab, Sh, Au_{LE}, Ha<Sa
Tot. Pb	3.21 (5,51)	0.014	Au_{LE}<Ha

Ab, Au_{LE}, Ha, Sh = lettuce batches from four farms Au_{CA} = cabbage batch from Al's farm
Sa = carrot batch from Sa's farm   Degrees of freedom are in brackets.

Figure 6-19: Relationship between soil DTPA-extractable Fe (mg kg^{-1}) and crop Fe (mg kg^{-1})

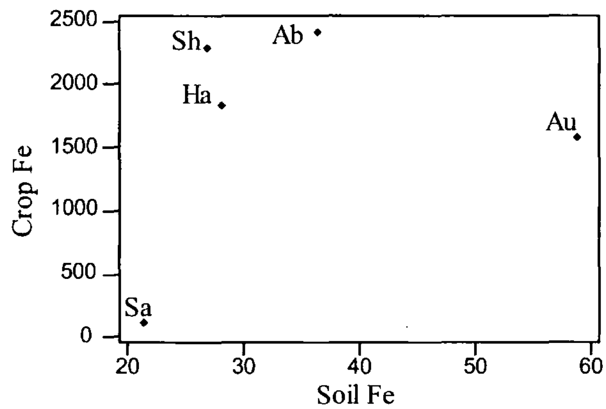


Figure 6-20: Relationship between soil DTPA-extractable Mn (mg kg^{-1}) and crop Mn(mg kg^{-1})

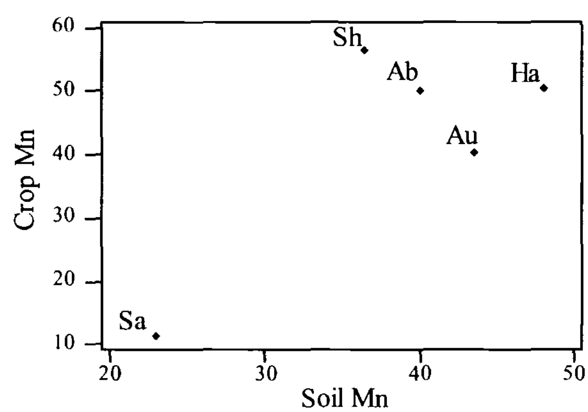


Figure 6-21: Relationship between soil DTPA-extractable Zn (mg kg^{-1}) and crop Zn (mg kg^{-1})

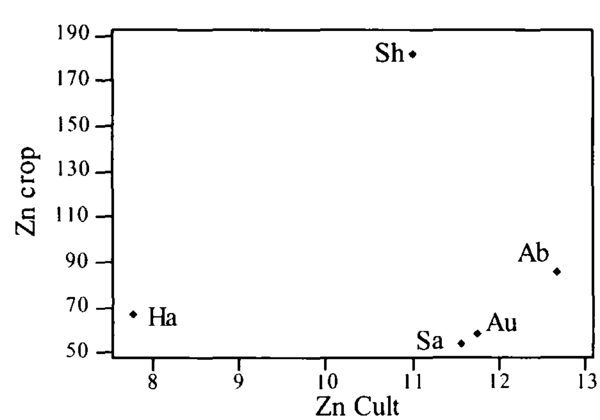


Figure 6-22: Relationship between soil DTPA-extractable Cu ($mg\ kg^{-1}$) and crop Cu ($mg\ kg^{-1}$)

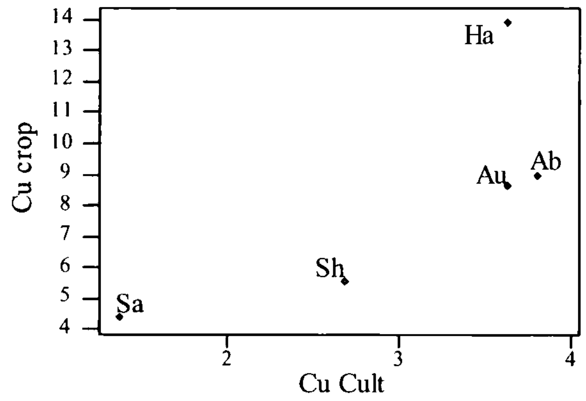


Figure 6-23: Relationship between soil DTPA-extractable Ni ($mg\ kg^{-1}$) and crop Ni ($mg\ kg^{-1}$)

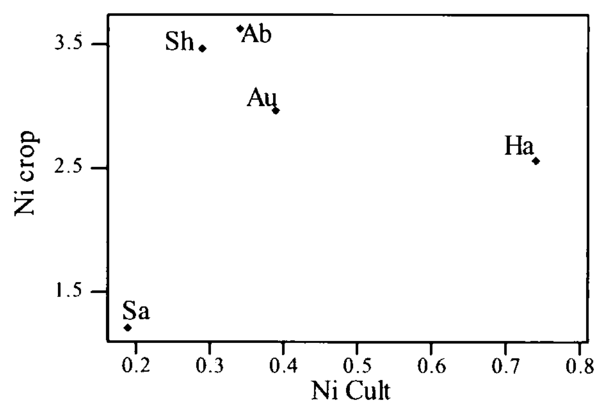


Figure 6-24: Relationship between soil DTPA-extractable Cd ($mg\ kg^{-1}$) and crop Cd ($mg\ kg^{-1}$)

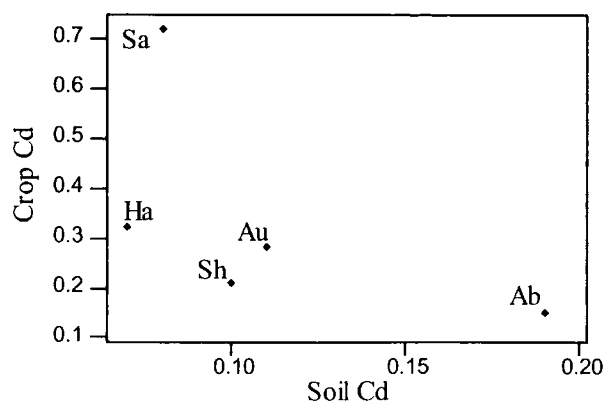
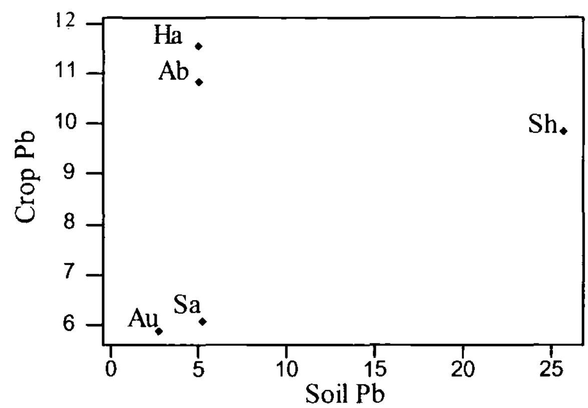


Figure 6-25: Relationship between soil DTPA-extractable Pb (mg kg^{-1}) and crop Pb (mg kg^{-1})



6.4.3 Discussion

The confirmation of whether there is heavy metal accumulation in the food chain can only be established by testing the levels in the crops themselves. It is not sufficient to do soil analyses alone. Several factors need to be taken into consideration. Firstly, it is well known that different crop species are tolerant of different levels of particular trace metals and, indeed, species that contain unusually high proportions of a particular metal are termed *hyperaccumulators* (Brooks, 1998). Secondly, it is known that cultivars of the same species can differ in their ability to absorb and translocate certain metals: for example, lettuce cultivars and Cd (Webber, 1980b). A visit to PADP (4.7.5.2) revealed that, in most cases, they only marketed one variety of a particular species, however there may be unofficial seed importation channels, which could bring in other varieties. Thirdly, there is a problem concerning mobility of the trace metals. Those elements, such as Cd, that are particularly mobile, can be translocated easily from the roots to the aerial parts of the plant (Williams, 1980). Thus, leafy crops tend to have the highest concentrations of Zn and Cd, which are mobile within the plant, whereas other metals, such as Pb and Cu, tend to be retained to a greater extent in the roots (Webber, 1980a). This issue was bypassed as only the edible parts of each crop were tested for heavy metals. Fourthly, there is uncertainty about the source of the contaminating element. Cadmium can be taken up from the soil through the plant roots but contamination can also be airborne and affect the aerial parts of the plants. Acid-washing techniques can remove this form of contamination (Martin *et al.*, 1980). There can also be a problem with soil contamination: some authors believe that Cd analysis is only warranted for leaves that are sufficiently free from soil contamination, such as inner lettuce leaves (Berrow and Burridge, 1980). These factors raised the question of whether the crops should be washed or not prior to analysis. Acid-washing was immediately excluded because consumers clearly do not use this to wash their produce, but it was impossible to determine if, and how thoroughly, market sellers and consumers washed the different vegetables and what quality water they used. In the end, carrots were washed with tap water to remove excess soil (also because market sellers were witnessed washing carrots and other root, but not leafy, crops in the Delimi river), whilst lettuce and cabbage leaves were not washed (although the external leaves were discarded). Furthermore, conditions in Nigeria meant that the crops could not be dried in a clean laboratory environment, but were sun-dried, and this could have resulted in additional contamination (although the short length of time involved makes this unlikely). Although the results should be examined with caution, the approach can be justified because of the uncertainty in hygiene standards. The contamination may result from heavy metals deposited on the surface of the crops rather than within, but if consumers are not washing their vegetables meticulously, they will still be acquiring the metals in their diet.

The results presented in section 6.4.2 can be examined in the light of research published in the literature. It is essential, though, to recognise that the determination of critical levels above which symptoms of toxicity are likely to manifest themselves in a particular crop, is quite complicated. Even though pot experiments can be carried out to study the effects of a single element on a crop species, when a range of contaminants is applied to the crop (for example, as sewage sludge and, in this case, as urban waste ash), it becomes very difficult to disentangle which contaminant is actually responsible for yield suppression. Berrow and Burridge (1980) applied different sludge types (uncontaminated sludge, Zn-rich sludge, Cu-rich sludge etc.) to lettuce and red beet, over the course of four years, to examine heavy metal levels. In many cases, the applications caused crop failure so that they were not able to measure heavy metal contents. They concluded that lettuce and red beet tolerated Zn in the order of 200-300mg kg^{-1} in dry tissue, but they were not able to determine critical levels for Cu and Ni because the Cu and Ni-rich sludges also contained high Zn levels, hence, crop stunting or failure could have been attributable to the Zn. Table 6-16 provides an indication of typical heavy metal ranges found in plants, and the critical concentrations above which toxicity effects are likely. These values can be compared to the data presented in Table 6-14, but as they are not targeted to specific crops they should only be considered a general guideline. None of the crops appear to have a problem with Fe deficiency, and whilst lettuce levels of Mn and Cu seem adequate, carrot and cabbage levels are below the deficiency threshold (even though they did not appear to be exhibiting any deficiency symptoms). A caution must be made that although leaf analysis of Mn is considered a useful diagnostic value, leaf Cu levels are not considered good indicators of Cu status (MAFF, 2000). Lettuce, carrot and cabbage levels of Zn are adequate. Concentrations of Ni, Cd and Pb of all crops fall within the normal range for plants.

Table 6-16: Typical ranges and critical concentrations of heavy metals in plants (mg kg^{-1}) according to Alloway (1990) and a ratings scheme for foliar examination of micronutrients in crops according to Landon (1984)

Variable	[a]Normal range	[a]Critical concentrations (1)	[a]Critical concentrations (2)	[b]Deficiency levels	[b]Adequate levels	[b]Excessive levels
Fe	-	-	-	<50	50-250	?
Mn	20-1000	300-500	100-7000	<20	20-500	>500
Zn	1-400	100-400	100-900	<20	25-150	>400
Cu	5-20	20-100	5-64	<4	5-20	>20
Ni	0.02-5	10-100	8-220	-	-	-
Cd	0.1-2.4	5-30	4-200	-	-	-
Pb	0.2-20	30-300	-	-	-	-

(1): Level above which toxicity effects are likely
(2): Values likely to cause a 10% depression in yield
Source: Adapted from [a]Alloway, 1990; [b]Landon, 1984.

Cadmium, lead and nickel are of additional concern because of their toxicity to humans and animals. Cadmium is a particular problem, because it can cause problems to human health at plant tissue concentrations that are not directly phytotoxic (Peijnenburg *et al.*, 2000). The maximum permissible levels in food are currently under revision by a joint FAO/WHO committee, the Codex Alimentarius Commission. The draft levels for Cd and Pb in vegetables proposed in 2001 by the Commission are presented in Table 6-17. From Table 6-14 it is immediately clear that only cabbage falls safely below the Cd limit for leafy vegetables; lettuce batches differ in their mean Cd concentrations, some means (Ab and Sh's) falling below the limit, and others (Au_{LE} and Ha's) above. Carrot, which would be grouped under the heading 'All other vegetables' has a mean concentration that is more than ten times the limit set for this group. As for Pb there is no doubt that all crops present mean concentrations that are 20 to 40-fold higher than the FAO/WHO maximum recommended level

Table 6-17: Draft levels (mg kg^{-1}) proposed by the Codex Alimentarius Commission Alinorm 01/12

Variable	*[a]Leafy vegetables*	*[a]Brassica*	*[a]Legume vegetables*	*[a]All other vegetables*
Cd	0.2	-	-	0.05
Pb	0.3	0.3	0.2	0.1

Source: Adapted from [a]FAO/WHO, 2001

The statistical analyses that tested whether there were significant differences between crop batches (Table 6-15), presented some striking results. Carrots had significantly less Fe, Mn, Cu and Ni than almost all lettuce batches. Similarly, cabbage had significantly lower Mn, Cu and Cd in respect to most of the lettuce batches, though there was more overlap between them. Carrot had significantly higher levels of Cd than all other crop batches, whilst Sh's lettuce had significantly higher Zn levels. By contrast, all crops had similar Pb levels, with only Au and Ha's lettuce showing a significant difference. If all crops had been grown on the same farm, there would have been the expectation that lettuce would have contained the highest concentrations of Zn and Cd, because of the mobility of the elements, while the carrots would have accumulated Pb and Cu (Webber, 1980a). This, clearly, has not happened, so an explanation must be sought in the differences in the soil levels. This assessment can only be done for the lettuce and carrots as no soil samples were taken from the farm on which the cabbage samples were grown. Figure 6-19 to Figure 6-25 show the relationship between soil DTPA-extractable levels of a particular variable and the total concentration in the crop. These figures, coupled with the information in Table 6-5, can help to explain the concentrations found in the crops. The first impression is that there may be a positive relationship between soil and crop levels in the case of Fe, Mn and Cu but there is a lot of scatter. What is important, though, is that Sa's farm (Table 6-5) contains significantly lower levels of these elements (and additionally Ni), and this explains the low levels in the carrots. In the case of Zn, Ni and Pb there does not seem to be any relationship, although there is a suggestion of a negative relationship for Cd. The absence of a strong relationship for Ni, Pb and Cd is unsurprising, as the DTPA extractant was developed for the purpose of predicting deficiencies for Fe, Mn, Zn and Cu in near neutral soils only. It was thought to be adequate for predicting Cd, but not Ni (Quevauviller *et al.*, 1996) or Pb (Connor, 1988). The absence of soil-crop relationship for Zn would appear strange but Table 6-5 revealed that, in any case, there were no significant differences in Zn levels between farms. Therefore, the clustering of crop concentrations is not unexpected, except for Sh's strikingly high mean. The most plausible explanation for this is that some of Sh's samples were contaminated by a Zn source (a few very large values support this hypothesis). Soil levels cannot explain why Sa's carrots contain such high Cd levels. Only Ab has significantly higher soil Cd levels, and yet his mean lettuce Cd does not differ significantly from the lettuce of the other farms. This contradiction can be explained either as the inaccuracy of the DTPA test or, more probably, the possibility that carrot is actually accumulating Cd (contrary to the view held in the literature that leafy vegetables should have a higher concentration of Cd compared to root crops). Lead results are problematic. Figure 6-25 suggests that there are highly unusual amounts of Pb in Ha and Ab's crops, considering that their soil levels are quite low and do not differ significantly from any other farm, except Sh and Au. Three explanations can be advanced. The first is that despite the information to the contrary collected at PADP (see above), there are, instead, different lettuce varieties, which explain the different accumulation. The second is that Pb may be in more than one plant-available form (and different forms are dominant in the different farms), and the DTPA soil test does not detect all these forms. The third is that there is a heavily localised contaminating source, however, neither farmer applied refuse ash to this second cropping cycle. This matter requires further investigation.

In conclusion, the levels of Fe, Zn, Ni, Cd and Pb appear to fall within the normal range for plants for all crops. Cabbage and carrots may indeed be deficient in Mn and Cu, but as the plants did not appear to be exhibiting deficiency symptoms further research into this is needed. The levels of Cd and Pb are of concern because of the implications for human health. Although the levels were within the typical range for plants, all crops had Pb levels that surpassed the FAO/WHO maximum recommended level, and carrots had excessive amounts of Cd.

6.4.4 An alternative source of heavy metal contamination: the irrigation water

To this point, the discussion has made the assumption that the source of heavy metal contamination of the soil (and consequently of the crops), is the soil itself. However, it is also possible that the Delimi river is a source (as it flows through Jos before passing through the farming area), so, to gain an understanding of possible nutrient and heavy metal input through irrigation water, two river water samples were collected towards the end of the dry season, when the water level of the Delimi was extremely low. As the analysis was semi-quantitative (4.4.5), the results displayed have an error margin of ±20% and, therefore, should only be considered a general indication of element concentrations.

Table 6-18: Semi-quantitative results on dissolved elements (mg l^{-1}) in Delimi river water

Variable	*River water*	*Variable*	*River water*	*Variable*	*River water*
Na	8234	***Fe***	331	***Ni***	0.43
K	6722	***Mn***	29.7	***Cd***	n.d.
Ca	6196	***Zn***	29.3	***Pb***	1.5
Mg	8696	***Cu***	2.5		

The quality of the Delimi river water must be assessed by using the WHO and the EC Guidelines for drinking-water (Table 6-19) as currently, there is no legislation in force to regulate the quality of irrigation water, although the European Commission (http://profiler.bgu.ac.il/resco/Funding%20Sources/EU%205fw/medaCall4Propo.html) has put out calls for proposals on irrigation water management, water resource quality, and use of non-conventional water resources. These guidelines are too stringent for irrigation water, but they provide a baseline for comparison.

Table 6-19: WHO and EC guidelines for drinking-water quality and typical concentrations of elements in drinking water

Variable	*[a]WHO Guideline value (upper limit)*	*[b]EC guidelines for drinking water*	*[a]Typical concentration*	***Delimi river water***	***Unit***
Fe	0.3	0.2	0.3	330	mg l^{-1}
Mn	0.5 (provisional)	0.05	0.02	29.7	mg l^{-1}
Zn	3	-	0.1	29.3	mg l^{-1}
Cu	2 (provisional)	2	0.1	2.5	mg l^{-1}
Ni	20	20	5	0.43	µg l^{-1}
Cd	3	5	1	n.d.	µg l^{-1}
Pb	10	10	5	1.5	µg l^{-1}

Source: Adapted from [a]WHO, 1996; [b]Council Directive 98/82/EC.

Base cations are predominant in the river water, followed by Fe, Mn and Zn. These last three surpass WHO guideline values, Cu is only slightly over the limit, whilst Pb, Ni and Cd are at extremely low or undetectable concentrations (Table 6-19). Therefore, the irrigation water does not appear to be a source of toxic heavy metals, but it contributes considerable amounts of base cations, which could affect the pH (this has already been discussed in 6.2.4.2).

6.5 WIDENING THE DEBATE AND SCALING UP

During the mid-1980s, research was carried out in the same study area to determine what the effects of cultivation were on soils of different reclamation ages. The average cultivated soil in the area had a pH of 6.9, and was characterised by very low organic C (1.09g $100g^{-1}$), low total N (0.094g $100g^{-1}$), medium-high available P (2.96mg $100g^{-1}$P—index 4), high exchangeable Ca and Mg (6.54cmol$_{(c)}$ kg^{-1} and 1.06 cmol$_{(c)}$ kg^{-1}, respectively), and medium levels of K (0.42cmol$_{(c)}$ kg^{-1}—index 2) (Alexander, 1986; 1996).

Alexander's (1996) analysis on samples collected in 1990, found that, on average, cultivation acted by significantly *increasing* the soils' top 20 cm pH, organic C, total nitrogen, exchangeable Ca and K, and available P, but significantly lowered the levels of exchangeable Mg. The statistical findings of the case study farms shows that cultivation significantly *decreases* organic C, total N, and exchangeable K and Mg, does not affect exchangeable Ca, and affects available P and pH in different ways, depending on which farm is examined. The two studies, though, should not be compared in these terms, because they used different sampling strategies (the issue of where control samples were collected from, in the two studies, is particularly important) and statistical approaches (Alexander's (1996) study pooled all cultivated samples and compared them to the pooled controls, whereas the current work carried out a two-way analysis of variance on cultivated and controls), and this would have influenced the results.

Instead, it is more useful to compare the average cultivated soils of the two studies, rather than compare the changes between cultivated and uncultivated sites. The soils share similar properties, but the 2000 case study farms present a noticeable increase in available P (from index 4 to index 6) and exchangeable K (from index 2 to index 3), in respect to the cultivated soil from 1990 (Alexander, 1996). In terms of the requirement for fertiliser, these are large changes, which are surely caused by the application of large quantities of NPK15:15:15 fertiliser. Indeed, section 6.3 indicated that there is some degree of over-application of IF on the study farms.

It has been stated at the outset of this chapter, that these results are the outcome of case studies and, therefore, cannot be representative of the whole farming system. However, if these results are combined with general survey and interview data on SFM strategies, for the whole farming area, they can provide a good estimate of what may be happening more widely.

The interviews in 5.1.1 revealed that farmers have a similar management strategy of combining IF and organic amendments, but that they rely predominantly on IF. Although there is some degree of variability in the approaches, most farmers apply a mixture of different IF types. In section 5.2.4, it was concluded that the Delimi farmers applied large quantities of IF, perhaps even over-applying it, and the most probable reason is that the compound fertilisers on sale on the Plateau are incorrect mixes for the soils there. Therefore, it is probable that across the whole farming area available P and exchangeable K have reached high levels because of the fertiliser inputs.

This is likely to be the case for the majority of farms, although, of course, there will be exceptions. Even between the case study farms there were differences. For example, there was a strong suggestion that Sa's SFM strategy was resulting in the accumulation of P in the soil, whilst Ha's was causing a decline in P levels.

It is also important to take note of the subtler trends. All farms displayed a significant decline in organic C, total N, exchangeable K and Mg, and available Mn levels in the cultivated soils in respect to the uncultivated sites. Although these changes may be too slight to be meaningful in terms of management practices, they may be symptoms of the early stages of a problem. The decline of these variables is most likely associated to the decline in organic matter. Cultivation usually does result in the reduction of organic matter, but as organic C levels are already very low in the soils of this area, how far can it decline before the system undergoes damage? Section 5.2.3 has already reported that there has been a widespread decrease in the use of organic amendments, both manure and town refuse ash, so it is probable that the decrease in organic matter is correlated to it, and that this is a problem that affects most farms in the Delimi area.

The question of whether heavy metals are accumulating in the system, as a result of the use of town refuse ash is a difficult one. None of the study farms had levels that were outside of the typical range for soils, except Sh who had high Pb levels. There was some suggestion that there was Zn, Cu and Cd enrichment in Sh and Ab's farms, which could be linked to the past use of considerable quantities of town refuse ash. The crops, however, contained large quantities of Cd and Pb. Carrots and a few lettuces batches surpassed FAO/WHO (2001) guidelines for Cd levels, and all crops surpassed the same guidelines for Pb contents (in fact samples could contain 40 times more than the guidelines). These high levels, though, do not seem to be linked to the soil contents and further research is required before any firm conclusions can be drawn.

Therefore, these results should not be extended to the whole farming area, particularly because it was very difficult to collect information on past practices concerning refuse ash.

The situation in Rayfield is likely to be quite different from Delimi. In Delimi, the process of decline in organic matter seems to have been brought about by the reduction in organic amendments. Certainly, if the situation continues as it is, farmers may shortly be faced with soil acidification through the use of IF. In Rayfield, there is a need for similar case study data, yet, because the use of poultry manure and ash is widespread, declining organic matter may not be a problem at this moment, or it may be a lot slower than in Delimi. On the other hand, Rayfield farmers are more likely to produce heavy metal contaminated crops because they use large quantities of town refuse ash from uncertain sources. This issue can be linked to the next chapter that provides some data on the potential contribution of heavy metals by refuse ash samples from different locations in Jos.

6.6 SUMMARY

This chapter contributes to the understanding of the impact of SFM strategies on the farming system by using case study farms. The sustainability (in terms of nutrient supply) of the farming practices on these farms has been examined by looking at overall nutrient and heavy metal status of the soil, and the impact of cultivation practices in the short and the long term; the outcome has been linked to specific fertilisation practices. In addition, the risk of heavy metal accumulation in the soil and in the food chain, through the application of town refuse ash, has been examined. To conclude, the results of the case studies have been compared to research carried out the past in the same area, and linked to information presented in Chapter 5 on general SFM, to assess how applicable they are to the wider farming area.

The next chapter will widen the debate on the risks posed by using urban waste ash as a part of the SFM strategy, by examining the chemical properties of ash samples collected around Jos and connecting the farmers' views on the mode of action of ash to research on ash as a soil amendment published in the literature.

7 THE ROLE PLAYED BY URBAN WASTE ASH IN THE FARMING SYSTEM

The previous chapter sought to gain an insight into the sustainability of the farming system through case study farms. As well as assessing whether farmers were maintaining soil nutrient levels, the research examined the risk of heavy metal accumulation in the food chain. A system cannot be considered sustainable if it is meeting crop demand but causing the introduction of contaminants. As town refuse ash plays an important role in the SFM strategies, there is a clear danger of the soil and crops being polluted. This chapter widens the research on town refuse ash, with an aim to determine the modes of action of the material in the farming system, and contribute to the assessment of the health risks associated to the practice of using ash in SFM (aim 3). This aim is addressed primarily through objective VI, but also with the help of information collected for objective I (which is presented in Chapter 5).

7.1 NUTRIENT AND HEAVY METAL CHARACTERISTICS OF URBAN WASTE ASH

The understanding of the mode of action of urban waste ash must start with the analysis of the properties of this material. This section reports on the chemical analyses of samples collected from the farms and from refuse heaps located in different neighbourhoods of Jos. The analysis of all samples gives an idea of the variability *across* areas, and the analysis of replicates from a single batch gives an idea of *internal* variability. These analyses are trying to determine whether ash can be considered a homogeneous material or not (objective VI).

7.1.1 Data

A total of 59 ash samples were collected for the analyses. Thirty-nine samples of ash were collected from different locations around the town and from a few farms at the study site (4.3.2). These samples can provide an impression of variability *across* locations. Another two sets (consisting of ten replicates each) are important to gain an impression of variability *within* fairly homogeneous batches. These are Ab's two batches of ash, which consist of a heap of town refuse ash (labelled 'refuse ash') brought by a JMDB truck, the other from the rubbish brought by the floods and strewn across his low-lying land (labelled 'river ash'), which was then collected and burnt.

The characteristics of the ash in terms of nutrient and heavy metal content have been summarised with simple descriptive statistics in Table 7-1 and Table 7-2. A simple way of judging variability is by dividing the maximum value of a certain variable, by the minimum value recorded. The results for every set are displayed in Table 7-3.

Table 7-1: Descriptive statistics for ash samples collected from different neighbourhoods in Jos

Variable	*Mean*	*Median*	*Standard error*	*Standard deviation*	*Variance*	*Minimum value*	*Maximum value*	*N° of samples*	*95% Confidence interval*
Org. C g $100g^{-1}$	1.96	1.73	0.21	1.31	1.73	0.06	4.36	39	0.43
Tot. N g $100g^{-1}$	0.15	0.14	0.02	0.11	0.012	0.01	0.48	39	0.04
pH	10.8	10.6	0.26	1.01	1.02	9.7	12.8	15	0.56
Tot. Na mg kg^{-1}	6,611	4,735	834	5,207	$2.71*10^{7}$	1,958	27,076	39	1,688
Tot. K mg kg^{-1}	29,843	28,841	1,778	11,101	$1.23*10^{8}$	4,760	55,630	39	3,598
Tot. Ca mg kg^{-1}	149,936	96,382	41,374	165,495	$2.74*10^{10}$	13,308	618,544	16	88,186
Tot. Mg mg kg^{-1}	14,679	12,388	1,306	8,153	$6.66*10^{7}$	1,624	33,414	39	2,231
Avail. P mg $100g^{-1}$	83.99	70.4	11.23	70.10	4,915	23.91	449	39	22.73
Tot. Fe mg kg^{-1}	9,741	7,382	1,378	8,605	$7.40*10^{7}$	1,420	35,404	39	2,789
Tot. Mn mg kg^{-1}	549	331	118	736	$5.41*10^{5}$	110	21,414	39	238
Tot. Zn mg kg^{-1}	483	311	108	676	$4.58*10^{5}$	42.1	3,753	39	219
Tot. Cu mg kg^{-1}	104	69	18.3	114.5	$1.31*10^{4}$	26.9	662.4	39	37.1
Tot. Ni mg kg^{-1}	28.6	26.6	2.1	8.9	78.6	19	49.7	18	4.4
Tot. Cd mg kg^{-1}	8.6	8.5	0.18	1.17	1.37	6.1	12.2	39	0.4
Tot. Pb mg kg^{-1}	404	69.8	192	1,198	$1.44*10^{6}$	26	6,539	39	388

Table 7-2: Descriptive statistics for two 'homogeneous' batches of ash

Variable	*Mean*	*Median*	*Standard error*	*Standard deviation*	*Variance*	*Minimum value*	*Maximum value*	*N° of samples*	*95% CI*
C river	**1.29**	**1.37**	**0.16**	**0.49**	**0.24**	**0.47**	**1.85**	**10**	**0.35**
N Ab	0.15	0.14	0.019	0.06	0.004	0.07	0.29	10	0.05
N river	**0.18**	**0.17**	**0.016**	**0.05**	**0.003**	**0.1**	**0.27**	**10**	**0.04**
Na Ab	12,937	12,322	1,396	4415	$1.95*10^7$	3,243	19,521	10	3,158
Na river	**1,910**	**1,928**	**57.5**	**182**	**$3.3*10^4$**	**1,540**	**2,130**	**10**	**130**
K Ab	19,578	20,924	2031	6,424	$4.13*10^7$	10,165	28,567	10	4,596
K river	**2,317**	**2,355**	**203**	**643**	**$4.14*10^5$**	**1,467**	**3210**	**10**	**460**
Ca Ab	95,724	81,539	14,057	44,453	$1.98*10^9$	55,489	208,665	10	31,799
Ca river	**7,704**	**7,328**	**437**	**1,383**	**$1.91*10^6$**	**6,022**	**9,628**	**10**	**990**
Mg Ab	7,584	7,046	410	1,296	$1.68*10^6$	6,338	10,006	10	927
Mg river	**473**	**464**	**14.4**	**45.6**	**2078**	**415**	**541**	**10**	**32.6**
P Ab	37.1	34.9	5.1	16.2	264	18.6	70.4	10	11.6
P river	**7.8**	**7.7**	**0.56**	**1.77**	**3.15**	**4.35**	**11.2**	**10**	**1.27**
Fe Ab	21,446	24,248	1,830	5,786	$3.35*10^7$	10,872	26,785	10	4,139
Fe river	**27,528**	**27,427**	**503**	**1,592**	**$2.53*10^6$**	**25,689**	**30,573**	**10**	**1,139**
Mn Ab	393	401	15.9	50.2	2,522	294	463	10	35.9
Mn river	**227**	**228**	**3.7**	**11.8**	**140**	**211**	**254**	**10**	**8.46**
Zn Ab	1,356	1,061	304	961	$9.23*10^5$	189	3,187	10	687
Zn river	**488**	**449**	**44.2**	**140**	**$1.96*10^4$**	**301**	**697**	**10**	**100**
Cu Ab	999	193	631	1,996	$3.99*10^6$	46.9	6,361	10	1,428
Cu river	**355**	**306**	**66.5**	**210**	**$4.42*10^4$**	**110**	**877**	**10**	**150**
Ni Ab	27.6	28.2	2.29	6.87	47.1	19.1	38.7	10	5.28
Ni river	**23.6**	**23.4**	**0.53**	**1.17**	**1.38**	**22**	**25.2**	**10**	**1.46**
Cd Ab	9.2	8.7	0.59	1.9	3.58	7.2	13.0	10	1.35
Cd river	**10.2**	**8.3**	**1.3**	**4.19**	**17.6**	**7.3**	**19.0**	**10**	**3.0**
Pb Ab	426	418	60.4	191	36,439	67.4	811	10	137
Pb river	**367**	**307**	**48.9**	**155**	**23,938**	**272**	**753**	**10**	**111**

Ab = Ab's town refuse ash samples. River = Ab's ash samples made from river-borne refuse. Organic carbon was only measured on River ash because there was little of Ab's ash available for the test. Units as for Table 7-1.

Table 7-3: Variability of three batches of ash for different variables

Variable	*Batch Ab-Refuse ash*	*Batch River ash*	*All ash*
Org. C (g $100g^{-1}$)	-	3.9	48
Tot. N (g $100g^{-1}$)	4.1	2.7	72.7
Tot. Na (mg kg^{-1})	6.0	1.4	13.8
Tot. K (mg kg^{-1})	2.8	2.2	11.7
Tot. Ca (mg kg^{-1})	3.8	1.6	46.5
Tot. Mg (mg kg^{-1})	1.6	1.3	20.6
Avail. P (mg $100g^{-1}$)	3.8	2.6	18.8
Tot. Fe (mg kg^{-1})	2.5	1.2	24.9
Tot. Mn (mg kg^{-1})	1.6	1.2	194.7
Tot. Zn (mg kg^{-1})	16.9	2.3	89.1
Tot. Cu (mg kg^{-1})	135.6	8.0	24.6
Tot. Ni (mg kg^{-1})	2.0	1.1	2.6
Tot. Cd (mg kg^{-1})	1.8	2.6	2
Tot. Pb (mg kg^{-1})	12.0	2.8	251.5

Values obtained by dividing the maximum by the minimum value of every batch to determine the extent of its variability. Nitrogen, for example, shows a four-fold difference in the 'refuse ash' batch, a three-fold difference in the river ash batch, and almost a 50-fold difference for the 'all ash' group.

7.1.2 Discussion

Section 7.1.1 has presented data on the potential nutrient and heavy metal contribution by ash (either town waste or farm waste-derived) to the soil of the farms. A better understanding of its wider potential in the agricultural system can be achieved by examining the chemical characteristics of samples collected from various locations in Jos. There are many examples of urban waste utilisation in agriculture. The emphasis of most research, though, has been on the characteristics of sewage sludge and compost, rather than waste ashes. Waste ash is obtained by incinerating various materials in incinerator plants (equipped with modern pollution control devices and operating at optimal conditions to ensure complete combustion), or as a by-product of other industrial processes. Examples are provided by studies on wood-fired and combination boiler ashes (Someshwar, 1996; Vance, 1996), coal-derived ash (Ghodrati *et al.*, 1995; Sims *et al.*, 1995; Wong and Su, 1997; Gorman *et al.*, 2000; Adriano and Weber, 2001), coal-fly ash mixed with biosolids such as sewage sludge and poultry manure (Schumann and Sumner, 1999; Shore, 2000), and municipal waste ashes (Zhang *et al.*, 2002). Alternatively, waste ash is produced informally by open burning of waste heaps in towns. This practice has been documented in various developing countries (Alexander, 1996; Alexander and Kidd, 2000; Phillips-Howard and Kidd, 1991; Bradford, Pers. Comm., 2001), but there seems to be a gap in the literature concerning the range of nutrient and trace metal levels in town refuse ash produced *in situ*. Therefore, the measurements made on a range of ash samples taken from different Jos neighbourhoods will provide some preliminary background values that can be compared to 'typical' ranges quoted in the literature, for similar ash materials and other waste-derived soil amendments.

7.1.2.1 Wood ash

The burning of organic matter provides readily available nutrients in the form of ash (Phillips-Howard and Kidd, 1991), and this material, particularly wood ash, has long been a traditional soil amendment (Vance, 1996; Foth and Ellis, 1997). Wood ash generally has a high pH, and has an excellent neutralising potential mainly because of its high Ca and Mg contents (Someshwar, 1996). The neutralising capacity is a function of the rate of reaction of ash in the soil that is controlled by the fineness of the ash particles. Wood ash has been shown to react faster than agricultural lime, resulting in higher initial increases in pH, that are generally maintained for shorter periods in ash-amended soil although, in some cases, the application of wood ash can result in long-term pH changes (Vance, 1996). The nutrient content of wood ash will, of course, vary depending on tree species, soil type and climate, as well as the conditions of combustion, collection and storage, but the predominant macro-elements include Ca, Mg and K (Someshwar, 1996), which are usually found in the form of carbonates because of the high temperature of burning (Foth and Ellis, 1997). There is some disagreement in the literature over the availability of P. Foth and Ellis (1997) argue that there are significant amounts of both K and P in wood ash, which are roughly equivalent to compound inorganic NPK fertilisers, in the ratio of 0-1-3 and 0-3-9, and that the availability of K ranges from 39% to 82%, whereas the availability of P ranges from 43 to 56%. Vance (1996) contends that P is not very soluble and plant available. Ultimately, the proportions of nutrients in wood ash, taken up by plants, will be a function of their concentrations in the ash, their relative solubility, the pH-induced changes in soil nutrient availability, and the crop requirements. Indeed, although ash additions can have positive effects by raising the pH and increasing nutrient availability, an excessive pH can actually induce certain deficiencies (MAFF, 1981; Vance, 1996). The most abundant heavy metals in wood ash seem to be Zn and Mn, with median levels of 329 and 3485mg kg^{-1}, respectively. Lead, Cu and B are the second most abundant, and they range from about 50 to 110mg kg^{-1}.

7.1.2.2 Coal-derived ash

Coal-derived ash is a widely produced material. Fly-ash is a residue generated by coal-fired turbines in electricity generating plants (Shore, 2000), but the ash can also be produced in the boilers of the pulp and paper industry, and mixed with wood-fired ash (Someshwar, 1996; Vance, 1996). Coal ash, like its parent material, contains almost every naturally occurring element, and could potentially supply K, P, Ca, Mg, C, Bo, Mo, Se, Ni, Cu, Zn and others (Shore, 2000), but the variability between ashes is high, and this has resulted in conflicting reports in the literature on the actual fertilisation effects (Schumann and Sumner, 1999). In contrast to wood ash, coal ashes do not commonly contain significant amounts of P or K, but they can have higher concentrations of trace metals, which can limit their usefulness (Vance, 1996). Of course, as in the case of wood ash, the high total concentration of any one element in the coal ash does not necessarily give rise to high plant available concentrations. Despite the positive role of coal ash as a liming material, the nutrient imbalances that this material can sometimes create has led to the testing of fly ash-biosolid mixtures: for example, fly ash has been shown to be an effective soil conditioner mixed with poultry manure (Schumann and Sumner, 1999), and sewage sludge (Wong and Su, 1997) and, in some cases, it has been successfully mixed with sewage sludge and water hyacinth (Shore, 2000).

7.1.2.3 Municipal waste ash

In some countries (such as Japan), where there is shortage of landfill space, incineration of all waste is widely adopted. A recent study has analysed the properties of food waste (FSA), horticulture and animal waste (HSA and AWA), sewage sludge (SSA), and incinerator bottom ashes (IBA) (Zhang *et al.*, 2002). The study found that all ashes had a similar major element composition, despite having different origins, but that for the trace metals, average values were not consistent with median values and for some elements, there were large variations. Unsurprisingly, the FSA, HSA and AWA had relatively lower minor and trace metal contents in respect to the SSA and IBA. Furthermore, the work demonstrated the importance of these wastes as liming materials, as their liming effect was approximately 10-30% of CaO, 40-55% of which was accounted for by Ca, the remainder being determined by the alkaline oxides of Na, Mg and K.

7.1.2.4 Comparing Jos town refuse ash to other ash

Farmers in Jos use ash produced by burning farm waste (leaves, grass cuttings, crop waste, branches), animal manures, and also urban waste. The type of refuse (which can contain a wide range of different organic materials) from which the town refuse ash was derived was, of course, unknown, as the rubbish is burnt periodically *in situ* along the roads, and only non-degradable objects remain (see Figure 7-1 for a typical heap of refuse in Jos). Therefore, it is expected that urban waste ash will share some common properties with wood ash and municipal waste ashes, but is likely to display high variability, especially in terms of the trace metals.

Table 7-4 lists data on the nutrient and heavy metal characteristics of different types of ashes, including urban waste ash from Jos. There are certainly many more examples in the literature (Goldin *et al.*, 1992, provide a thorough review of the characteristics of incinerator bottom ash, fly ash and combined ash), but the purpose of this table is not to comprehensively review the characteristics of different ashes but simply to allow a preliminary comparison between Jos ash and other ash types. The ranges provided here are sufficiently representative of the variability of each ash type, as the authors of each source had already reviewed existing data or, at any rate, had carried out extended sampling. The dominant macro-nutrients in urban waste ash from Jos are Ca, K, Mg in that order, followed by the heavy metals Fe and Mn. These nutrients are predominant in the other ashes but with different importance. For example, Fe is present in larger quantities than Mg or K in SSA, but in very much lower quantities in FSA. The median Mn value in Jos is low, despite its very large range, and especially when the relatively small ranges and large median values of the other ashes are considered. Macronutrient variability is high in all ashes, but what is obvious is that the variability in SSA and FSA from Japan, is relatively less in respect to Jos ashes and wood-boiler ashes. This is because in the latter case, the burning environment (temperature, oxygen levels, wind speed) will vary to a considerable extent, and this will affect the amount of particulate matter/soot contained in the smoke that is blown away. The particulate matter could contain various elements, and this could be one factor determining the variability. The most important trace element in Jos ash is Zn, followed by Pb and Cu. Of the three elements Pb has the widest range but a strikingly low median, relative to the range. Nickel and Cd are considerably lower and also are characterised by quite a restricted range.

Although Table 7-4 clearly illustrates that all ashes are dominated by Ca, and to a lesser and differing extent by K, Mg and Fe, it is difficult to make generalisations regarding the trace elements. The Jos ash obviously presents a high variability that, in some circumstances, (e.g. Mn and Pb), can surpass the variability of the other ashes (including CFA and SSA), despite the relatively low median values. Cadmium in Jos ash is, perhaps, striking because the highest value recorded is only double the lowest value recorded, and the lowest value (6.1mg kg^{-1}) is certainly quite high when compared to the lowest recorded values for the other ashes (from not detected in WBA1 to 1.7mg kg^{-1} in SSA).

Figure 7-1: Typical refuse heap found in Jos

Table 7-4: Comparison of mean and range values of selected element concentrations of Jos urban waste ashes to other ashes

Element	*JOS*		*[a]SSA*		*[a]FSA*		*[b]WBA1*		*[b]CFA*	*[c]WBA2*	
	Median	*Range*	*Median*	*Range*	*Median*	*Range*	*Median*	*Range*	*Range*	*Median*	*Range*
Na $g\ kg^{-1}$	4.7	2.0-27.1	17.6	15.9-32.1	32.4	17.8-49.6	-	-	-	-	-
K $g\ kg^{-1}$	28.8	4.8-55.6	16.2	14.1-26.1	14.8	6.78-20.7	-	-	-	27.9	1.9-130
Mg $g\ kg^{-1}$	12.4	1.6-33.4	24.8	21.5-34.6	23.8	10.9-25.5	-	-	-	9.7	3.2-24.7
Ca $g\ kg^{-1}$	96.4	13.3-619	100	65.9-163	78.2	32.6-149	-	-	-	180	35.9-966
Fe $g\ kg^{-1}$	7.4	1.4-35.4	39.8	7.02-48.6	1.4	0.64-2.79	-	-	-	-	-
Mn $mg\ kg^{-1}$	331	110-21,414	2,000	470-2,510	1,000	170-1,650	3485	30-9,130	25-3,000	2,430	0.33-7,820
Zn $mg\ kg^{-1}$	311	42-3,753	3,276	384-4303	281	139-799	32.9	6.3-220	14-3,500	316	35.2-1,250
Cu $mg\ kg^{-1}$	69	27-662	2,838	1,740-4,775	95.4	48.3-126	68.2	3.4-210	14-2,200	70.4	37.7-207
Ni $mg\ kg^{-1}$	26.6	19-50	213	156-369	67.7	36.5-104	16.4	ND-97.3	1.8-4,300	-	-
Cd $mg\ kg^{-1}$	8.5	6.1-12.2	6.6	1.70-15.6	1.8	0.11-9.77	3.6	ND-20.8	0.1-130	-	-
Pb $mg\ kg^{-1}$	69.8	26-6,539	547	330-999	14.5	12.0-30.9	61.5	22.7-220	3.1-2,120	-	-

Refuse ash (JOS), sewage sludge ash (SSA), food scrap ash (FSA), coal fly-ash (CFA), wood-boiler ashes (WBA1&2). 'ND' = Not Detected. '-'= Not measured.
Source: Adapted from [a]Zhang *et al.*, 2002, extracted with HNO3-HClO4-HF; [b]Someshwar, 1996; [c]Vance, 1996.

The variability in the Jos ash was expected because of the nature of urban waste and the sampling strategy adopted. It emerged from an interview with a representative of the JMDB (see Appendix C), that Jos North and Jos South are serviced by only four tipper trucks. This obviously means that collection is restricted to high priority areas and this leads to the development of informal dumping grounds along the sides of the roads, especially in proximity to the markets. There is no control over what is dumped and, periodically, the refuse heaps are burnt to reduce the space they occupy. The waste is varied. Large amounts of the waste are organic materials (for example, waste food from the markets) but there are considerable proportions of plastic, paper and metallic rubbish. Thus, iron fragments (such as condensed milk cans, tomato cans, wire) could easily be the source of the high levels of Fe found in the waste (a similar interpretation was given by Zhang *et al.*, 2002, for high Fe levels found in incinerator bottom ash). Batteries can be a source of several elements amongst which, Cd, Ni, Pb and Zn; dust, dirt and clay particles in paper can be a source of Ca; magazine paper is a notable source of Fe, Pb and Zn; other papers can be a source of Cu and Mg (Lisk, 1988). Perforce, ash samples were collected with no knowledge of what material they had originated from, and what potential sources of contamination they had been near. The refuse heaps are obviously not homogeneous, so samples could have been randomly contaminated or relatively clean. What is important with this strategy is that it mimicked what the farmers themselves would obtain. If they bought a truckload of refuse from the town, it could contain polluting materials that would not be removed until after the waste was burnt. Even if they collected ash directly from town they would have no knowledge of what waste had collected there previously.

7.1.2.5 Comparing Jos town refuse ash to other waste-derived amendments

It is harder to compare materials such as sewage sludge, compost, municipal solid waste and manure, with the refuse ash because the physico-chemical properties (that affect plant availability of nutrients or contaminants), will be entirely different. Furthermore, the reaction in the soil can also affect plant availability, so that high concentration of a particular element will not necessarily result in contamination. Composts, for example, contain high levels of heavy metals and can greatly increase the amounts of total and extractable levels in the soil to which they are applied. Nevertheless, trace metals are not taken up in the same proportion as the enhancement in the soil: indeed the availability of trace metals in field conditions relates poorly to the extractability in acetic acid measured in the laboratory. This means that the relative insolubility of heavy metals in the field is likely to be a function of pH, soil organic matter, and Ca content of municipal composts (Gray and Biddlestone, 1980). All the same, it is useful to compare the broad characteristics of different materials. Table 7-5 summarises data on the nutrient and trace metal properties of different materials: urban waste ash from Jos, household waste ash from the Kano close-settled zone, coal fly-ash, municipal solid waste (MSW), sewage sludge (SS), compost, and cattle manure. The table presents mean values and it must be remarked that given the extreme variability in some wastes, the mean alone is not a good descriptor but ideally should be examined alongside the range or the coefficient of variation. The change in units depending on which variable is being examined should be noted (i.e. organic C is measured in g $100g^{-1}$, but available P in mg $100g^{-1}$, etc.). In terms of pH, organic C, and total N, urban waste ash is similar to coal fly-ash, even if not as low as fly-ash for the latter two components. It is quite similar to household waste ash from Kano in terms of total N, K and Mg, but it is extremely rich in Ca. In contrast, the other refuse-derived materials are rich in organic C and N (the sewage sludges have particularly high N contents), but have a lower pH. For available P, urban waste ash is not as rich as sewage sludge but is higher than the composts or municipal solid waste. The ash from Jos also contains very large mean amounts of Ca, Mg and K, compared to the other materials, although cattle manure from the Ethiopian highlands contains similar amounts of K. The mean Mn content of Jos ash is in the same range as cattle manure, but is lower than the example provided of coal fly-ash. Manganese concentration is in the same range as 'mature' compost and, perhaps, cattle manure, whereas Zn levels are far higher than the coal fly-ash, the cattle manure, and the clean, and very clean, compost, but lower than one of the sewage sludge examples. Copper presents roughly the same picture. Nickel content is considerably lower than the other materials. Cadmium levels are quite high, particularly when compared to the clean and mature composts but not the sewage sludge. Lead levels are in the same range of the MSW and higher than the other materials.

Urban waste ash is likely to be an effective liming material because of the high pH and Ca, Mg and K contents (that as in wood ash are likely to be in the form of carbonates), but in respect to the other waste-derived materials it will contribute little organic matter and N. Available P levels are medium-high in relation to the other materials. The ash can contribute fairly high levels of Mn, Zn and Cu, especially when compared to coal fly-ash, the 'clean' composts and cattle manure, but is quite clean in respect to Ni. Cadmium and Pb may be of some concern because levels are quite high.

Table 7-5: Mean nutrient and trace metal properties of various soil amendment materials

Chemical Properties	*Jos urban waste ash*	[a]*Kano ash*	[b]*Coal fly-ash*	[d]*Municipal solid waste*	[b]*Sewage sludge*	[d]*Sewage sludge*	[d]*Immature Compost*	[d]*Mature Compost*	[c]*Clean compost*	[c]*Very clean compost*	[e]*Cattle manure*
pH	10.8	-	12.4	7.18	7.39	6.61	7.16	7.86	-	-	-
Org. C $g100g^{-1}$	1.96	-	0.15	25.81	27.8	31.87	18.41	10.58	-	-	-
Total N $g100g^{-1}$	0.15	0.21	0.047	1.47	7.03	4.3	1.16	1.01	-	-	1.83
Total Na $g\ kg^{-1}$	6.6	-	-	-	-	-	-	-	-	-	-
Total K $g\ kg^{-1}$	29.8	16.6	1.4	6.5	2.3	4.1	5.6	6.1	-	-	21.3
Total Mg $g\ kg^{-1}$	14.7	5.6	5.1	-	3.5	-	-	-	-	-	5.6
Total Ca $g\ kg^{-1}$	149.9	2.5	59	-	12.6	-	-	-	-	-	16.4
Avail. P $mg\ 100g^{-1}$	83.99	-	-	40	-	190	30	60	-	-	-
Total Fe $g\ kg^{-1}$	9.7	-	25	-	7.3	-	-	-	-	-	10.8
Total Mn $mg\ kg^{-1}$	549	-	-	266	-	114	274	454	-	-	777
Total Zn $mg\ kg^{-1}$	483	-	43.2	536	1268	454	504	671	280	75	92
Total Cu $mg\ kg^{-1}$	104	-	37.9	270	979	212	199	149	90	25	24
Total Ni $mg\ kg^{-1}$	28.6	-	-	235	-	154	312	649	-	-	-
Total Cd $mg\ kg^{-1}$	8.6	-	3.51	6	13.7	2	8	4	1	0.7	-
Total Pb $mg\ kg^{-1}$	404	-	-	438	-	107	101	200	120	65	-

'-' = Not measured.

Source: Adapted from [a]Harris and Yusuf, 2002; [b]Wong and Su, 1997; [c]Hart and Pluimers, 1996, Dutch guidelines; [d]Pascual *et al.*, 1997; [e]Lupwayi *et al.*, 2000.

7.1.2.6 The safety of town refuse ash from Jos

The urban waste ash poses a particular problem for interpretation of the 'safe' levels of trace elements, as guidelines have been derived from studies conducted on compost, municipal solid waste or sewage sludge. Since it is likely that the availability of these heavy metals is different in refuse ash, the application of the guidelines requires caution. Furthermore, the assessment of the safety of urban waste ash in Jos will be complicated by the variability of the material. Table 7-3 shows that the levels of some elements in the ash samples displayed a very high variability. Predictably, the variability in the 'all ash' batch is far higher than the variability of the 'refuse ash' batch and the 'river ash' batch. It could be as small as two-fold for Cd and Ni, but was over ten-fold for all other elements, reaching 195-fold and 250-fold differences for Mn and Pb, respectively.

On the whole, the variability of 'refuse ash' is a little higher than that of 'river ash' (as well as the mean and median values), and this too was expected as the 'river ash' rubbish had been mixed so was more homogeneous than the truckload of town refuse ash. Generally, for both batches the difference between minimum and maximum tended to be three to five-fold, with a few noticeable exceptions. These were mainly for the 'refuse ash' batch, and consisted of a 11-fold difference for Pb, an 17-fold difference for Zn and a 135-fold difference for Cu. The 'river ash' ash batch was unusual for K and Cu, which showed a 15-fold and 8-fold difference, respectively. This analysis shows that when the refuse materials that produce the ash are of limited types and are mixed thoroughly (as in the case of the river ash heap), the end material is quite homogeneous, although for some elements (such as Cu) there can be exceptions. The problem is that, for the most part, the town refuse which the farmers have access to is far from being mixed and homogeneous, so that the application of one batch of ash may lead to the formation of 'pockets' of very high levels of a certain trace metal on the farm. This variability limits the applicability of the regulatory recommendations for the disposal of waste materials on agricultural land because even if it was found that median values could be considered 'safe', pollution could arise through the application of a particular batch of contaminated ash (cf. Rayfield farmer's problem with tyres).

The legislation on maximum limits of heavy metals in waste-derived materials is difficult to interpret and to apply for a variety of reasons. Both the EEC and USEPA have set maximum permissible levels of heavy metals in sewage sludge but while USEPA presents one single value, the EEC presents a range, and there is no agreement between the two organisations (Table 7-6). It also would appear that there is new work on heavy metal limits by the Commission of the European Communities (in a 3rd draft of a working document on sludge produced in 2000) (Thornton *et al.*, 2001), where it appears that only the lower limit of the range of values provided in Council Directive 86/278/EEC (Table 7-6) is being used, and that the Cd limit has been lowered to 10mg kg^{-1} dry matter. The EC has also issued a directive to establish the ecological criteria for the award of a Community eco-label to soil improvers (Commission Decision 98/488/EC). These guidelines present maximum permissible levels of trace elements (Table 7-6) for a soil improver to deserve the eco-label: these are similar to the Dutch guidelines for the definition of a 'clean' compost (Table 7-5). A further complication is that legislation is targeted at the utilisation of sewage sludge, and does not provide guidelines for compost or municipal solid waste or any other solid material. For this reason, Zucconi and De Bertoldi (1987) (as cited by Pascual *et al.*, 1997) proposed that a multiplication factor of about 0.3 should be used to adapt EEC sewage sludge specifications for compost.

If the EEC guidelines are adopted, mean and median values of ash for all trace metals are comfortably below the lower limits for sewage sludge (even if the new limit of 10mg kg^{-1} for Cd is adopted) and, indeed, the Cu, Ni and Pb median values would meet the criteria for an 'eco-label'. If Zucconi and De Bertoldi's (1987) correction factor for compost is applied to the EEC's lower limits, then Cd median levels and Cd and Pb mean values exceed these new limits. Unfortunately, it is clear from the statistics in Table 7-1 that there is great variation between samples, so that the mean or median cannot properly describe the situation. If the range is employed, and Zucconi and De Bertoldi's (1987) limits are used for reference, it becomes clear that there are instances for all variables where the maximum suggested levels are exceeded. Cadmium and Pb are of particular concern for different reasons. Relative to the other variables, the Cd range is not wide, but the minimum value is high when compared to the minimum value found in sewage or compost (Table 7-5). If the new working (but not in force) limit of 10mg kg^{-1} adopted by some EEC bodies is considered, and if the Zucconi and De Bertoldi correction factor is applied, transforming it to 3 mg kg^{-1} for compost, the range of approximately 6 to 12mg kg^{-1} for urban waste ash in Jos is cause for concern. Lead is problematic because of the very wide range. The maximum value is well above any of the permissible limits and although half or more of the sample values would fall below the Zucconi and De Bertoldi limits, some ash samples are greatly contaminated.

Table 7-6: Maximum permissible EEC and USEPA limits of trace metals for sewage sludge disposal on agricultural land and for the awarding of an EC eco-label to soil improvers and Zucconi and De Bertoldi's suggested limits for compost.

Pollutant	*[a]EEC sewage sludge*	*[b]Zucconi and De Bertoldi compost ([a] *0.3)*	*[c]EC eco-label for soil improvers*	*[d]USEPA sewage sludge*
Zn	2500-4000	750-1200	300	2800
Cu	1000-1750	300-525	100	1500
Ni	300-400	90-120	50	420
Cd	20-40	6-12	1	39
Pb	750-1200	225-360	100	300

Source: Adapted from [a]Council Directive 86/278/EEC; [b]Zucconi and De Bertoldi, 1987. (In: Pascual *et al.*, 1997); [c]Commission Decision 98/448/EC; [d]Thornton *et al.* (2001).

In conclusion, it is suggested that present day ash does not contain excessive levels of Zn, Cu and Ni. Cadmium levels may be below EEC guidelines but the levels are sufficiently high to be of some concern. Although median Pb levels are low, very high peak levels mean that there is potential for highly localised contamination. More research is needed into which forms of these elements are dominant in the ash, and which conditions affect their plant-availability once they are applied to the soil.

7.2 POSSIBLE MODES OF ACTION OF ASH

As already discussed in 4.3.1, the isolation of the proper effects of ash would require rigorous laboratory and 'in the field' experiments. At this stage, this was not logistically possible in Jos, so the explanations on the modes of action of ash have to rely on combining information on the general nutrient characteristics of ash (7.1), with farmers' explanations and with information from other published studies. The final part of this section discusses the health risks associated to using town refuse ash, and what perceptions the farmers have of this issue.

The farmers in the study area were interviewed on their knowledge about the effect of ash on soil fertility. The interviews revealed that the farmers have a considerable body of knowledge, which in some cases, was shared by all farmers and, in other cases, appeared to be the observations of a few individuals. Accessing and understanding, and then linking this knowledge to 'scientifically-conducted' experiments is an issue that has been reviewed in Chapter 2.

The collective knowledge seems to make a distinction between different types of effects: whether ash is applied as a soil amendment or as crop leaf treatment. The action on the soil can be further subdivided into physical and chemical, even though the farmers themselves did not express it in this way. Although it is a problematic decision, these effects will be considered separately, because it aids the understanding of possible modes of action of ash. Phillips-Howard and Kidd (1991) reported on the farmers' observations on the effects of ash: they noted that ash ranked amongst the weakest fertilisers, but was considered persistent, it softened the soil, was readily available and was the cheapest material. The farmers in the current research also listed these attributes of ash, though it was no longer as readily available as in 1991. Additional information was provided by the semi-structured interviews, which were specifically targeted at providing a clearer understanding of the mode of action of ash. The broad themes emerging from these interviews will be presented and interpreted in the light of work carried out on other types of ash.

7.2.1 Effects of ash on the soil

Farmers generally remarked that ash increased the strength ('*karfi*') of the soil, so that if ash was applied the amount of IF required would be greatly reduced (by up to half the amount). This is probably a direct effect of the large amounts of base cations in the ash, or an indirect effect, as the ash raises the pH and, hence, increases base availability. Ash is a particular source of K, which the soil analysis, conducted on the four case study farms, suggests is required (6.3.3). Ash was particularly effective when reclaiming degraded land or opening up new land and, indeed, any attempt at reclamation without using ash for several consecutive years would be unsuccessful. Work by Alexander (1996) in these areas has shown that the farmers' overall strategy is highly efficient and successful, and there are also examples in the literature of mineland reclamation using coal fly-ash (Gorman *et al.*, 2000). Of course, there are instances in other parts of the world, where coal fly-ash has not been very successful in reclaiming mineland but this was probably because of the inappropriate pH and buffering capacity (Pichtel *et al.*, 1994). Coal fly-ashes can vary in pH from 4.5 to 12.0 depending on S content of the parent coal (Adriano and Weber, 2001), so not all are suitable for reclamation.

In this instance the action of ash is three-pronged: as in the case of wood ash (Someshwar, 1996), the waste ash has a high pH, Ca and Mg content, which will help neutralise the acid soils and increase nutrient availability (Phillips-Howard and Kidd, 1991); the ash will directly add nutrients to the soil that can be taken up by plants; the ash will add organic matter and improve soil structure. The use of wood or household rubbish ash is clearly the original strategy adopted by farmers in the Plateau, and still today many farmers mix wood ash (obtained from commercial ovens where a lot of cooking takes place) and poultry manure, as part of the fertility management strategy, especially in the Rayfield area (5.1.2). The large-scale use of town waste as a source of ash is probably a relatively recent development that arose in peri-urban areas in the late 1970s or early 1980s (the practice was certainly witnessed in 1982 in Rayfield—Alexander, Pers. Comm.). The exact reasons for the adoption of refuse waste are not readily identifiable: it may have been the consequence of expanding dry-season vegetable production, the increase in motorised transport, and the development of a refuse collection system in Jos; associated with a decline in IF availability, which would have pushed the farmers to seek alternative fertiliser sources. Some farmers stated that town refuse ash was a better amendment than farm waste ash because it contained many more substances in it that made it 'stronger'. Another characteristic of ash identified by the farmers was its persistence in the soil ('*dadewa*'): you could observe its effects for up to two-three years, unlike IF that would disappear within a season. It is reasonable to suppose that ash contains nutrients that are not in an immediately available form but will be released in the longer term when the organic matter is degraded, in similar fashion to animal manure.

Although the physical effects of ash on the soil were not investigated during this research, the farmers made observations that seem consistent with the outcome of studies on the physical effects of wood ash or coal-fly ashes. Almost all farmers commented that ash made the soil soft ('*laushe*') and less sticky. This could be the result of the addition of organic matter that over time is thought to assist soil crumb formation (MAFF, 1981), or the consequence of the large amounts of Ca that also participate in soil aggregation (Brady and Weil, 1999). The pozzolanic (ability to cement or aggregate particles) nature of ash has been observed in other work (e.g. Adriano and Weber, 2001). The perceived benefits in soil structure are possibly an outcome of the liming effect of the ash. It is noteworthy that the farmers in the study area describe the effects of ash in a similar fashion to UK farmers describing the effects of lime on the soil's physical properties. MAFF report that: "*It is widely held by farmers that liming improves the structure of heavy soils, reduces stickiness, lightens cultivation and makes it easier to break down clods and obtain a satisfactory tilth. In the days of horse cultivations, it was often said that after very heavy applications of burnt lime 'four-horse land' became 'three horse land or even less.*" (MAFF, 1981, p.10).

One farmer in Delimi made an intriguing statement to the effect that a heavy soil that retained a lot of water would retain less water and, consequently, become softer under ash application, but if ash was applied to a soil that did not retain much water, it increased its water-retention capacity. This last effect has been demonstrated in work on coal fly-ash where large additions of coal fly ash significantly increased water holding capacity (WHC) and plant available water (PAW) (Adriano and Weber, 2001), and, in some instances, significantly decreased water flow through the soil (Ghodrati *et al.*, 1995). These changes have been attributed to the predominance of silt-size particles in coal fly ash: the large surface area of spherical-shaped particles is conducive to increasing total porosity and shifting pore size, so as to increase micro-porosity of the soil, thereby increasing water holding capacity (Ghodrati *et al.*, 1995). It is probable that much research that has documented the increase in water-holding capacity following the application of ash, concentrated on soils that were problematic in terms of moisture-retention capacity (e.g. Ghodrati *et al.*, 1995). There does not appear to be any research on heavy textured soils amended with coal fly ash, but the addition of ash to a heavier-textured soil will promote the formation of clay aggregates (thereby improving soil structure) and this will result in the increase in macro-pores, which will increase water flow. In the U.K., peat used to be applied for similar purposes: on sandy soils it would increase water-holding capacity, whilst on clay soils it would improve drainage. In relation to texture, farmers also sometimes observed that while ash or manure resulted in the 'softening' of the soil, IF made the soil 'hard' and difficult to work.

Another physical change attributed to ash by the farmers was the change of colour of the soil. For the farmers, the outward manifestation of the increase in 'strength' of a soil is given by the darkening of the colour (Figure 7-2): in the Hausa farmer's judgement, a black soil (black is opposed to red) is a fertile soil. The change of soil colour was reported in work by Adriano and Weber (2001), where they maintained that application of coal fly ash visibly darkens soil colour.

Figure 7-2: Farms with (right hand photo) and without (left hand photo) ash application

7.2.2 The benefits of ash to the crops

As well as using ash to improve soil characteristics, farmers employ ash to benefit the crops. This is an area that is very difficult to explain and interpret because farmers were less consistent with their explanations, and there also seems to be an area where a perceived action on the soil apparently results in better crop characteristics. Farmers apply ash in two different ways, and this seems to be related to the explanations they give on the action of ash, although no farmer explicitly made the distinction. The farmers may apply the ash at the beginning of the season *before* preparing and breaking up the land for cultivation and, in this case, the benefits discussed relate to soil characteristics. This is carried out especially on new farms/plots. This practice was never observed during the 2000/2001 study period but has been witnessed in this area in the past (Alexander, Pers. Comm.).

Farmers may also apply ash once the crops are quite well developed, in which case, most of the ash falls on the actual plants and relatively less falls on the soil. The major impact of ash, in this circumstance, is to change the crop colour to a darker shade of green (see Figure 5-1), which the farmers say is very important because it makes the produce more attractive to a potential buyer. The change of colour is quite noticeable, and one farmer put forward the explanation that the darker green colour was a result of an increased chlorophyll production (this farmer had received secondary school education, and was speaking in English, rather than Hausa). This is the most likely explanation: in this instance, the ash probably acts by addition of Mg (as Table 6-13 shows, large amounts can be added through ash application) through foliar fertilisation that results in an increased formation of chlorophyll. The likelihood that ash acts through foliar fertilisation aids the interpretation of some other, more ambiguous statements. Farmers generally tried to explain that ash and IF had separate but complementary roles but most were unable to express themselves further, or provided explanations that were difficult to understand. The clearest statement was that: "*Ash makes the leaves do well and modern fertiliser makes the roots do well*". It is probable that the farmers have some intuitive understanding about the acquisition of nutrients through the leaves, from the ash.

Ash is also considered to be a pest repellent: farmers commented that although it did not kill pests, it tended to prevent their attack and it was particularly effective in combination with chemical pesticides in powder-form. This particular benefit of ash certainly deserves further investigation, to shed light on what exactly repulses the pests.

As already discussed, farmers explained that the application of ash softened the soil, making it easier to break up and prepare. Yet, this was not the only benefit, as it also facilitated the expansion of a crop's roots through the soil medium. For example, carrots would develop and expand better if ash was applied to the soil. There was no strong consensus as to the situations that required ash application. Some farmers advocated the use of ash in all circumstances, while others explained that it was unnecessary on soft soil (for example on low-lying land that received the river's '*laka*' or mud during the flood season). Some farmers applied ash to all crops, other farmers targeted specific crops, and although it was agreed that tomatoes required ash, there was disagreement in regards to the other crops. This may be significant information but, on the other hand, it may be the result of each farmer's special circumstances. For example, the farmers who stated that they applied ash to all their land may not have had areas of soft soil and so omitted to specify that soft soil did not require ash. And maybe farmers who applied ash consistently to all crops were working on poor land where the complementary action of ash was necessary or, perhaps, they had a problem in obtaining sufficient quantities of IF.

7.2.3 Location-specific knowledge

This discussion has shown that, on the whole, farmers in Delimi are very knowledgeable about the effects of ash. Their knowledge, though, can be patchy and this may be the outcome of their particular experiences (see Chapter 5). That knowledge is site-specific was observed during the interviews in Rayfield. Rayfield farmers use large quantities of ash and poultry manure, in combination with IF. Like the Delimi farmers, they explained that these materials had complementary and distinct roles, and that the application of ash reduced the need for IF. It also was beneficial because it made the crops greener, it softened the soil, and acted as a pesticide. Additionally, they noted that it made the crop expand, but unlike the Delimi farmers, they were referring to the aerial portions not the roots. Tomato would produce more branches that would increase the number of flowers and, hence, the fruit production. A leafy crop like lettuce would expand and produce more leaves. One farmer actually explained that ash benefited the leaves themselves by acting as a fertiliser: the application of ash would make the crop dusty but after three weeks the crop would have absorbed all the dust and would be growing vigorously. Other farmers warned that not too much ash should be applied because it could 'rot' the crop, by drying out the leaves, especially if there was dew in the mornings.

7.2.4 Conclusions

In conclusion, this section has, indubitably, shown that farmers are skilful and knowledgeable in the use of waste ash, and are keen observers of the modes of action and effects of this material. However, as already remarked upon in section 5.2.2.1, knowledge is site-specific and depends on the circumstances that the farmers are exposed to. So, although there are certain recurrent ideas, there are differences in the interviews obtained from Delimi and Rayfield. A problem is that farmers' expertise does not seem to extend to the health risks brought about by shifting from the home production of farm waste or household waste ash to urban waste ash, probably because the polluting substances are rarely present in concentrations that will cause acute toxicity. This point will be elaborated in the next section.

7.3 THE HEALTH RISKS ASSOCIATED TO USING TOWN REFUSE ASH

It is noteworthy that (excepting the one individual in Rayfield mentioned in point 9 in 5.1.2), farmers were not conscious of any dangers in applying town refuse ash. In the light of the data presented in 7.1.2, 6.1.2 and 6.4.3, this could become a problem.

The discussion in 7.1.2 leads to the conclusion that Cd levels in town refuse ash are below EC guidelines, but are sufficiently close (and consistently so, as variability is low) to be of some concern. Median Pb levels are low but a few samples contain some very high peak levels that could lead to highly localised contamination. The soil analysis (6.1.2) suggests that the levels of heavy metals in the case study farms fall within the typical range for soils, with the exception of Sh, whose cultivated and control are unusually high in Pb. However, the concentrations in the soil may not be good indicators of plant uptake, so crop samples were analysed for heavy metals and it was found (6.4.3) that Cd levels in carrot and Pb levels in all crops surpassed the WHO/FAO (2001) maximum recommended level for vegetables. In the case of carrot, there was a suggestion that it was accumulating Cd (as soil levels were much lower than where the lettuce crops were being grown).

Although there is need for further research (to carry out studies to find an extractant that will provide soil results that will correlate well with crop levels; to find which proportion of heavy metals in ash is plant-available; to establish more firmly which crop species are accumulating trace metals), the significant finding is that some crops are taking up large quantities of Cd and Pb. Whether this is caused by the application of contaminated ash to the soil is not certain but, in any case, the continued application of ash containing high Cd or Pb levels will aggravate the situation. The discovery that ash application results in crops turning a darker shade of green (probably through foliar fertilisation), is a further complicating factor. The foliar uptake of heavy metals from anthropogenic emissions has been documented in many studies (e.g. Greger *et al.*, 1993; Alaimo *et al.*, 2000), and it is speculated that in Jos, heavy metals may be absorbed directly from the ash deposited on the leaves. Even if soil contamination through ash application was slow and did not have a large impact on the crops, the direct application to the surface of the leaves could still result in the build-up of heavy metals to dangerous levels. This matter needs urgent investigation.

The key problem with using ash as an amendment is its variability. With the exception of Cd, most heavy metals are present at non-toxic levels. Nevertheless, the high variability indicates that there is the danger of a farmer obtaining a heavily contaminated batch, which could either contaminate the soil (this is the most likely explanation for Sh's high soil Pb contents), or even cause crop failure (this happened to the farmer in Rayfield, who used ash obtained from refuse that had tyres in it during the burning process). So, although ash appears fairly 'safe' to use, and indeed, because of the high base cation content (that gives it excellent liming properties) and micro-nutrient contribution it is beneficial, the possibility of 'pockets' of contamination does exist.

Yet, on the whole, farmers do not seem to be aware of these dangers. The transition from using domestic household refuse ash to town refuse ash holds dangers, but they do not perceive them, unless they experience an episode of crop failure, which they can relate to the use of ash.

The practice of burning refuse prior to sorting is partly responsible for the presence of heavy metals in the ash. Sorting the refuse before burning would reduce the amount of contamination, although not eliminate it completely. Unfortunately, this strategy to decrease the problem of heavy metal contamination (for the benefit of the consumers), could aggravate the problem of pathogen contamination (to the detriment of the farmers, or whoever sorted the waste first). One of the reasons for burning the waste is that, to some extent, farmers were aware of the dangers in handling raw municipal waste (although the ease of handling burnt waste relative to the unpleasantness and arduousness of sorting raw waste is another strong motivating factor). One farmer explained that he even went as far as burning cattle manure to ash because his father had taught him that it killed the 'germs'. This point leads on to a wider debate about the risks associated with preparing and using town refuse ash.

In this thesis, the complexity of the experimental and analytical procedures did not allow the assessment of all the risks posed by the utilisation of town refuse ash. Therefore, the work was limited to the analysis of heavy metals (7.1). There are, nonetheless, various other problems.

The problem of pathogen contamination has already been mentioned above. Farmers reduce the health hazards of handling raw waste by burning it before sorting. It is probable that, in most instances, the high temperatures of burning are sufficient to destroy all pathogens, because they reach temperatures that are higher than the composting process, even if lower than modern incinerator plants. If a sufficient temperature is reached during composting (60 to 70°C), most pathogens are destroyed (Déportes *et al.*, 1995), thus the waste ash should be sanitary. Nevertheless, further studies need to be conducted to ascertain this.

The environmental implications of incineration and ash disposal have been reviewed for other settings, and it is likely that the informal, uncontrolled process of burning town refuse in Jos will be subject to the same or greater risks. Incineration of municipal solid waste can result in particulate and gaseous emissions containing heavy metals, polychlorinated dibenzodioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), polycyclic aromatics (PCAs), polychlorinated biphenyls (PCBs), acids and other compounds. All these substances are also present in the ash itself and this can eventually result in contamination of land and water (Lisk, 1988). As well as changing the soil's chemical properties, coal fly-ash has also been shown to affect microbial respiration, even though little is known about the subject (El-Mogazi *et al.*, 1988). These dangers are applicable to the situation in Jos and, additionally, the open burning of waste is even more dangerous as it will result in toxic emissions that are liberated directly into the atmosphere (with no attempt at detoxification), and because this takes place at ground level, it represents a possible health hazard to humans.

To conclude, there is need for further research into the health risks attached to using urban waste, and more particularly, into ways in which these risks can be reduced. Ash has been an important component of the reclamation strategy, through its neutralising properties. As Alexander (1996) has pointed out, unless they are carefully managed, most IF are acidifying (particularly those commonly available to Jos farmers) so, without the counteracting action of the ash, the soils are likely to acidify quickly, reducing the availability of nutrients, and in the long-term causing reduced yields. Thus, it is important to encourage farmers to continue using this amendment, while minimising the health hazards.

The way to do this is the problem. The simplest and most efficient way forward would be to have a large-scale, modern incinerator plant, equipped with pollution control devices, where waste would be sorted prior to incineration. Ash could be homogenised and tested at regular intervals to monitor contamination. Then, there would have to be a good distribution system, to return the ash to the farmers at the appropriate moment. This would solve the problem of waste disposal in Jos and, at the same time, provide the farmers with a useful soil amendment. An alternative would be to set up a composting plant that would be cheaper and simpler, it would solve the problem of pathogens, although it could still have a problem of heavy metals. The current situation in Nigeria, though, would not allow the accomplishment of any of these plans. The government needs to release vast amounts of funding for an incinerator or compost plant to be set up (and to ensure continuation and maintenance), and, given the current state of the waste disposal service throughout Nigeria, and the scant support of farming activities, this is unlikely to happen in the near future.

It is similarly difficult to approach the problem at the small-scale, regulating farmers' practices. Farmers would have to be convinced that using town refuse ash can be dangerous (and as many are illiterate, this is difficult), so that they would either sort prior to burning (which would minimise heavy metal contamination, but increase the incidence of diseases because of the handling of the raw waste?) or use relatively 'clean' sources of ash. One option is to use wood ash from commercial cooking (as many farmers in Rayfield were doing), but as farmers in Rayfield were complaining that ash was scarce, would this realistically supply all farmers?

Ultimately, the responsibility rests with the government, because only the government has the resources to solve this issue. It could introduce recycling at the household level, and provide dumping grounds for 'safe', organic material that the farmers could go and collect for themselves, or alternatively improve the waste collection system and bring the unsorted waste to a sorting and incinerating plant, before distributing the ash. Either way, solving this matter will require a considerable starting investment.

7.4 SUMMARY

This chapter has contributed to a better understanding of the role ash plays in the farming system, by providing preliminary data on the chemical properties of this material, and, by discussing its possible mode of action in the light of the farmers' opinions and other studies carried out on similar materials, such as coal-fly ash. Furthermore, it has reviewed the actual (supported by the thesis' data) and potential (which need further investigation) health risks attached to using town refuse ash in SFM.

Chapter 8 will now draw together all the important issues related to soil fertility management (presented in Chapters 5, 6 and 7), and place them into the broader context of general farming problems.

8 THE POSITION OF SOIL FERTILITY MANAGEMENT IN RELATION TO WIDER FARMING PROBLEMS

As indicated in Chapter 1, the initial design of this research project had a component based on participatory trials. Section 4.6.3, however, describes how farmers gave their co-operation but did not participate, and advanced various hypotheses as to why *participation* did not work. One of the possible explanations was that farmers were beset by other short-term problems, so that they could not really consider a long-term issue, such as the maintenance of soil fertility. Thus, a SFM project was not considered a priority by the farmers.

Throughout the fieldwork period it became increasingly obvious that farmers did have very urgent and pressing problems, and, therefore, to conclude this analysis, it is important to relate the major findings concerning SFM to the broader context of general farming problems (aim 4). This provides a better understanding of how important soil fertility really is, in relation to other issues on the Jos Plateau.

In order to do this, objective VII can be broken down into more specific research questions:

1. Which farming problems do farmers claim they are faced with?
2. What is the governmental extension service's viewpoint on farmers' problems and how do these views relate to farmers' perceptions?
3. How do all these views relate to the thesis' findings?

Section 8.1 will present the outcome of the interviews (4.7.2.2) and the survey data on farming problems (4.7.1), without any discussion. Section 8.1.1 will provide an analysis of these farming problems, and relate them to past research on the same topic in this area. Section 8.2 will present an overview of what PADP perceive farmers' problems to be, and relate this to farmers' perceptions. It will illustrate (particularly through the example of a World Bank irrigation scheme) how different perceptions of the same problems can cause considerable tension and a breakdown in communication. Section 8.3 will place the thesis' findings on soil fertility into this context to try to provide a detached assessment of how soil fertility should be ranked, in relation to other farming problems.

8.1 WHAT ARE THE GENERAL FARMING PROBLEMS AS PERCEIVED BY THE FARMERS?

Seventeen farmers were interviewed on what they identified as their major problems (4.7.2.2). There has been no attempt at ranking because the interviews were quite free. Each farmer was asked to discuss his problems but with no constraint of having to list them in order of importance. Some farmers preferred to give a ranking, others seemed to address the first few issues in order of importance and then list the rest randomly, others preferred listing them chronologically, as they appeared during the farming season. Some farmers were less communicative than others. The only point where farmers seemed to agree strongly was the need for capital (point 1 below).

1. Money was essential. A farmer needed money to start the business, he needed money to continue the business. Several respondents suggested that with money virtually all problems had a solution, without access to money the business was doomed to failure.
2. Access to capital was very difficult. Farmers could not benefit from credit facilities, as banks do not provide loans without some form of collateral. If a farmer had done well the previous season he might have some capital left over to re-start his business after the rainy season. If he had not made a profit he needed to finance his farming with money from a secondary activity, or borrow from someone. Middlemen could advance money but according to one farmer not more than 2000 Naira.
3. Farming inputs hinged on the issue of capital. If a farmer had capital he could hire labour to clear the land in preparation for farming, he could afford to buy seeds, fertiliser for the crops, and petrol for the pump engine to irrigate. He could purchase a pump engine when it broke and piping and hose. He could also buy pesticides to ensure that crops would not be damaged by pests, and continue to feed his hired help.
4. Gaining access to a pump engine is a complex problem that will be used as a case study in section 8.2.
5. Petrol to operate the pump engines was another source of difficulty. Whereas IF was expensive but available, petrol was expensive and very difficult to obtain because of a national petrol shortage at the time of study. Farmers were forced to carry their pump engines to the filling station because their ID cards (which were introduced originally to obtain a jerry can of petrol that otherwise is not allowed in Nigeria) were no longer recognised. This was because some people had started forging ID cards to obtain subsidised petrol, and even some farmers had taken advantage of their cards to obtain petrol and re-sell it on the black market. Farmers, in any case, complained that they were often mistreated by the owners of the petrol stations, who would keep them waiting for hours, and perhaps refuse to sell petrol to them. The situation could be so desperate that some farmers just went

directly to the black market, particularly because the full tank of petrol was not sufficient to irrigate the whole of the farm (the situation may have changed and improved since the study period—August 2000-May 2001—as it seems that the State government has started taking serious action against people running the black market —Brown-Peterside, Pers. Comm., November, 2001).

6. Another complaint concerned the scarcity of certain seeds, such as cabbage and leek. Farmers could not always find the seeds of certain less common crops (some thought it was a deliberate shortage engineered by the salespeople to raise prices), they often risked buying expired seeds which would not germinate (they noted that the seeds they bought at PADP were good quality but expensive and very often PADP did not have enough in stock), some crops would not produce seed (carrots and cabbage for example, which are also very expensive), and in any case there were few varieties on the market, and they were very anxious to try out new varieties.

7. Pests were another problem mentioned quite frequently. Pest damage was particularly prevalent during the hot season (March/April), and cabbage was always heavily infested with greenfly. This forced them to purchase pesticides, which in pure form were quite effective but expensive, but could sometimes be found in adulterated form on the market.

8. Farmers complained of the lack of governmental support. They felt that they should be encouraged and listened to, as they are primary supporters of the economy but in reality there were few interventions on the part of the government (which in any case stopped at the large-scale farmers). They felt that the government could aid them by adopting a series of policies concerning subsidising IF (they did already, but it was very limited and arrived at the end of the dry season, when farmers were collecting their last crops and pausing for the rainy season); creating allocations of petrol specifically for farming activities, setting up refrigeration facilities (to improve storage of perishable produce); or establishing a canning factory to absorb the over-production of tomatoes.

9. Marketing issues are a diverse group of complaints and are perceived differently. Some farmers complained of the over-production of the same crop, the consequent flooding of the market and the fall in prices. They attributed this to the lack of education of the farming population as a whole and the inability to diversify sufficiently. Others complained of the control of the market by middlemen, who (particularly in times of over-production) could force the prices below production costs. The farmers felt that they had no alternative but to sell because their crops were perishable and the middlemen were aware that they could not refuse to sell for very long. Some farmers did not feel the impact of the middlemen, because they sold to relatives in the business, but others did not think the solution was straightforward. A few people had suggestions to improve the situation: minimum prices could be fixed by the government; refrigerated storage facilities would lengthen shelf-life of

the produce and give them time to search for a buyer; a canning factory could provide an outlet for the excess production of tomatoes; a farmer-controlled market, like the one being built by FUA (Appendix C) on Bukuru Road (close to the Building Materials Market), would cut out the middlemen. There were mixed views on the FUA market. Some farmers were very optimistic about it and thought it would allow them to cut out the middlemen, but others thought that it had been planned badly with no parking space for big trucks and that, in any case, the stalls were already owned by important personalities in the town and not by farmers.

To a great extent the outcome of the interviews was supported by information collected during the survey described in 4.7.1, yet, some problems that were discussed during the interviews did not emerge at all during the survey. Table 8-1 presents a list of problems (from the survey) and the percentage of farmers who declared being affected by a particular problem in Delimi and Rayfield. Farmers generally mentioned three or four problems each, except for those who declared that capital was the overriding problem, as with sufficient capital all other problems could be resolved (results not shown here).

Table 8-1: Type of problems experienced by farmers in Delimi

Problem	*Percentage of farmers in Delimi*	*Percentage of farmers in Rayfield*	*Problem*	*Percentage of farmers in Delimi*	*Percentage of farmers in Rayfield*
Finance	67	82	*No credit facilities*	1.9	2
Petrol availability	63	58	*Cost of engine oil*	1.9	2
Obtaining fertiliser	46	60	*Unfriendliness of PADP*	1.9	0
Pump engine	35	30	*Ash availability*	1.9	0
Seeds' availability	12	0	*Transport*	0	4
Obtaining labour	7.6	30	*Pesticides*	0	2
Weeds	0	14	*Cost of hose pipe*	1.9	0
Having enough food	0	8	*No problem*	1.9	0
Obtaining poultry dung	0	6	*Refused answer*	1.9	0
No government support	3.8	0			

8.1.1 Discussion

It is interesting to contrast the outcome of the questionnaire survey and the semi-structured interviews. Even though the key topics emerging from the interviews were matched by the ranking from the survey, some topics were rarely or not mentioned at all in the survey. Marketing was a particularly obvious example. It was never mentioned in either the Delimi or Rayfield surveys but was discussed quite frequently during the interviews. There are two possible explanations for this. One, is that farmers felt less comfortable with the format of the questionnaire survey and only mentioned the most immediate problems, but found space to discuss marketing during the interviews. The other is that during the formulation of the question 'What are the major problems in farming?' during the survey, the farmers only considered aspects of production whilst during the interviews they understood that 'problems in farming' was open-ended and could comprise any stage in the process. The differences in the information gathered with the two methods, illustrate how these two are complementary, and how the full understanding of the outcome of a questionnaire survey can only be achieved when it is supported by interview information.

8.1.1.1 Major problems

Overwhelmingly, farmers stated during the interviews that finance was their major constraint. They believed that as long as they had access to capital, little was beyond their purchasing power. It was interesting to note that even if farmers mentioned problems, other than finance, for the most part they were related to capital. For example, they complained about the cost of IF, pump engines, petrol, and other farming inputs such as seeds, hoses and engine oil. The survey results (Table 8-1) showed that, in Delimi, farmers identified 14 problems: the top ranking problems were the availability of finance (67%), petrol (63%), IF (46%), pump engines (35%), seeds (12%) and labour (7.6%). In Rayfield, 12 problems were identified, the main ones being availability of finance (82%), IF (60%), petrol (58%), pump engines (30%), labour (30%), and the problem of weeds (14%). Both areas shared the top four problems, although the weighting differed slightly. Apart from petrol availability, all the remaining important constraints are linked to capital/finance availability. Petrol is more complex. It *should* have been cheaply available from filling stations at a government-set price, however, as a result of continuing shortage farmers complained bitterly of the mistreatment they received by the owners of the filling stations, the long queues, the uncertainty of whether they would obtain petrol there or not, and the fact that they were forced to purchase from the black market because of the time involved in obtaining cheap but insufficient petrol at a regular filling station. They were quite clear in the fact that they thought that the government was responsible for providing petrol and that, indeed, as their labour was so important, the government should make special provisions for providing petrol, especially for *fadama* farmers.

8.1.1.2 Factors affecting the prioritisation of problems

It is important to recognise that the prioritisation of problems is heavily linked to the farmer's individual circumstances and to the relative 'urgency' of each problem. This is where the survey information is complemented by the in-depth interviews. For example, in the survey, petrol availability was mentioned more frequently than obtaining a pump engine, so would appear to be the most important problem. The interviews, though, revealed that the survey did not necessarily reveal the magnitude of the problem. All farmers considered petrol a problem because it was a constant necessity. However, when it occurred, the loss of the pump engine was far more serious than the petrol problem. All farmers struggled to obtain sufficient petrol for irrigation, but no farmer was forced to stop his activity because he could not acquire petrol. On the contrary, when a farmer's pump engine broke beyond repair, unless he could borrow one from his neighbours or relatives, he was forced to stop dry-season farming. In the fieldwork period, three men to whom this had happened, or was about to happen in that season were identified, and many more did not own a pump engine, but were surviving by borrowing. The interviews showed that farmers who ranked obtaining a pump engine as a top priority were invariably those who either never owned one or no longer owned one, and were forced to borrow from neighbours or relatives. The remaining farmers did not mention a pump engine as one of their concerns because, although the pump engine was difficult to obtain in the first place and was expensive, it could then be used for up to six years.

Thus, the framing of problems was highly subjective. Farmers who felt particularly disappointed in the lack of support by the government, framed their problems in terms of what they thought the government should do to help them (subsidise IF, establish a canning factory to absorb the over-production of tomatoes, distribute pump engines with low down-payments, set up petrol stations to exclusively serve dry-season farmers, provide credit facilities). Other farmers could be especially obsessed with problems that affected them specifically: as mentioned above, a farmer could be concerned about a pump engine if he did not own one, a farmer who had expanded far from the river emphasised the cost of piping to transport the water, a farmer who specialised in uncommon crops (celery for example), explained that he could not find the seeds easily, a farmer who specialised in cabbage complained of pestilence and the high cost and relative ineffectiveness of pesticides, while a farmer who had not made much profit at the market was concerned about the problem of middlemen. All these problems could affect the farmers in turn, but it is generally the most urgent problem that commands the greatest attention, even if it is not necessarily the most important.

Differences in prioritisation of problems can also be linked to differing farming environment conditions, and this was most apparent by looking at the survey differences between Delimi and Rayfield. Rayfield farmers placed considerable importance on the issue of obtaining labour, and keeping the plots free from weeds. This is related to the greater average farm size in Rayfield compared to Delimi (4.7.1), where farmers never mentioned weeds as a problem. A consistent proportion of Delimi farmers considered seeds an issue, as they were concerned with availability, lack of varieties, cost and poor quality. Seed problems did not emerge at all from the Rayfield survey, and this could be variously explained by the fact that Rayfield farmers specialise in different crops, purchase from different markets where there is greater seed variety, or have fewer monetary constraints when commencing the farming season because they are large-scale farmers.

Some minor problems differed amongst the two areas and, once again, these are determined by different local conditions: Rayfield farmers mentioned the need of having enough food to feed their labourers, availability of poultry manure, and transport. The first problem is possibly linked to the larger numbers of hired labourers. The problem of availability of poultry manure also emerged from the interviews on the use of fertilisers (5.1.2), but it is striking that, although during the interviews farmers complained that ash (which is combined with poultry manure) was scarce, during the survey this was not mentioned. It suggests that, although farmers complained of the decreasing availability of both during the interviews, the actual problem is obtaining poultry manure. The transport problem is probably determined by the fact that the area is remote from built-up surroundings so the availability of transport is much more of a necessity. The purchase of fertilisers and other inputs, and the transport of crops to the market, requires motorised transportation, whereas in Delimi, the Farin Gada market is sufficiently close so that the farmers can head-load some produce, or walk there to purchase a small quantity of IF that can be transported by hand. As discussed in section 5.2.3, farmers in Delimi are relying almost exclusively on IF, whereas Rayfield farmers are still purchasing pick-up loads of poultry manure and ash, so they require motorised transport.

In Delimi, there were a variety of minor problems, many of which were not encountered in Rayfield. For example, only a small proportion of farmers complained of the unavailability of ash, however, during the interviews on fertilisers (5.1.1) it became apparent that farmers would have liked to use ash, but they found it difficult to obtain. Section 5.1.1.1 advanced some explanations as to why farmers in Delimi had apparently ceased using ash. There were a diverse range of complaints, but the most probable reason is that, in the past, farmers in Delimi were used to obtaining ash cheaply through JMDB. With the reduction of the number of tipper lorries and the mounting problem of petrol availability, it became harder and costlier to obtain a tipper load from JMDB, so that, in the end, only large-scale farmers could afford it. This may be a reason why ash availability was not mentioned as a problem in Rayfield: most farmers in that area are large-scale, so they can continue purchasing tipper or pick-up loads of ash, even though they are being forced to reduce the quantities. Farmers in Delimi additionally complained about the general lack of government support, which again was not mentioned in Rayfield: this was expressed directly as lack of government support (3.8%) and, indirectly, as unfriendliness of PADP (1.9%) and lack of credit facilities (1.9%). During the interviews on farming problems the lack of governmental support emerged on numerous occasions, but it was also mentioned spontaneously, in conversation. There was the general feeling that as they, the farmers, were important supporters of the economy, they should be given recognition and the opportunity to present their views. Instead, they felt that the few initiatives to encourage farming either failed because corrupt government officials embezzled the funds, or only reached the large-scale, rich farmers, who had connections with government officials, and were able to ensure that all the aid was given to them. This feeling of exasperation with the government was probably acute in Delimi, because of the deteriorating relations with PADP, which had been amicable in the past (Phillips-Howard, 1992b) over a World Bank sponsored project (see 8.2 for a detailed analysis of this situation). This is one possible reason why this was mentioned as a problem in the survey in Delimi but not in Rayfield. A second reason why Rayfield farmers may not have mentioned this problem is that they are larger-scale farmers, so they have the resources that can solve many of the problems that Delimi farmers find difficult, so there is less bitterness. Alternatively, some Delimi farmers may have viewed the survey as a means of communicating with the government (a plausible explanation, as they often stated during the interviews that they wanted their views passed on to the government), whereas Rayfield farmers may not have been aware of the full research activities connected to the survey.

A final point to make is that the timing of the survey could also be relevant to the type of problems mentioned by the farmers. The survey was carried out in December, when the climate is at its coolest. Pest infestation becomes a serious problem in the hot months (March-April), so presumably, if it had been repeated then, farmers would have mentioned pests and pesticides more frequently. Similarly, if the survey had been carried out during a major harvesting period, farmers might have mentioned transport and marketing issues more frequently.

8.1.1.3 Comparison of current farming problems to problems in the area in the past

It is interesting to compare the current results to a similar study conducted in 1990, where farmers were surveyed and interviewed, so as to pinpoint how significant indigenous knowledge is in the improvement of their own conditions (Phillips-Howard and Kidd, 1990). The two surveys (1990 and 2000) show some similarities but the interpretation of problem ranking is different in the two studies. Phillips-Howard and Kidd (1990) reported that all problems articulated by the farmers were directly related to finance and, therefore, although shortage of cash was identified only by 52% of farmers, it was, in fact, the limiting factor. The top ranking three problems were unavailability of chemical fertiliser, shortage of cash, and lack of pump-engines (followed by unavailability of seed, pestilence, unavailability of transport, lack of irrigation hose, and feeding of labourers). The current situation is similar to 1990, as farmers view capital as the fundamental constraint to farming activities and, moreover, most problems that are not articulated as financial are, nevertheless, connected to it. Unlike 1990 though, the vast majority of farmers were explicitly ranking cash shortage as the major limitation, and many explained that virtually any problem could be solved with sufficient capital. There was greater diversity in problems in 2000 than in 1990, and, of course, the priority of the problems had changed. Although cash, chemical fertiliser and pump engines ranked highly in both surveys, the problem of petrol availability was non-existent in 1990, in contrast to the high prioritisation in 2000. Conversely, farmers mentioned the problem of pestilence and unavailability of transport in 1990, but this did not occur in 2000. It is probable that there has been an increase in motorised transport since 1990, which explains why it was not quoted as a problem, but why pestilence was not mentioned is uncertain. It is possibly related to a question of timing of the survey, rather than the absence of a problem of pestilence, as the 2000 survey was conducted in December, when the weather is most unfavourable to pests. Later in the season, the incidence of pests increased and during the semi-structured interviews a few farmers started mentioning the problem of pests, particularly in respect to cabbage. The 1990 survey was carried out from February to May.

Phillips-Howard and Kidd (1990) discussed the influence of the '*kawo*' (bring) mentality in the articulation of problems in 1990. Outsiders (foreigners and government officials) are expected to bring material inputs in return for knowledge sharing. They speculated that farmers might not have expressed other serious problems, if they did not perceive them to be '*kawo*-solvable'. They ascertained that farmers were well-able to define their major problems, and intended and ideal solutions, but believed that the '*kawo*' mentality could have played a certain role in the definition of these problems, although they were not entirely sure to what extent. The information collected in 2000 does not really support the idea of the predominance of the '*kawo*' mentality, because, in the first instance, a very large percentage of farmers responded in the survey that cash was the predominant constraint and frequently elaborated that all other problems were subordinate to the problem of finance. Similarly, during the semi-structured interviews, farmers were explicit about the fact that capital was a critical element in their business and dominated all aspects of production. They connected the lack of capital to the absence of credit facilities, and explained that, especially at the beginning of the farming season (when cash had been exhausted in the rainy season break), they required capital to start their business, but, unless they could borrow from family members or friends, or had secondary activities to support their farming, they were unable to do so. This idea was expressed a few times in the survey and more frequently during the discussions. It could be argued that this is still '*kawo*' mentality as it implies '*kawo kudi*' (bring money), but interviews suggested that farmers were not expecting 'gifts', either from the interviewer or from the government. They expected to have to pay for their inputs, but what they wanted from the government was facilitation, so that they would have access to credit in times of hardship and would return the loans when they had a source of money, for example, during harvest period.

In the second instance, farmers conveyed preoccupations (even in the survey) that were not directly '*kawo*-solvable'. For example, they stated that they had problems in acquiring petrol, labour, poultry dung and ash and this was more dictated by the scarcity of these inputs than their high cost. Similarly, the farmers in Rayfield who mentioned weeds as a problem in their farming activity were not expecting a solution (such as a herbicide, as these chemicals are virtually unknown in Nigeria), but were highlighting a significant production constraint.

8.2 HOW DO FORMAL INSTITUTIONS PERCEIVE FARMER PROBLEMS AND HOW DOES THIS RELATE TO FARMERS' PERCEPTIONS?

The last decade or so has seen the increasing popularity of participatory approaches to technology development in agricultural research (e.g. Okali *et al.*, 1994). Reij and Waters-Bayer, (2001a) however, believe that experiences in supporting farmer experimentation have been of limited benefit, and that 'transfer of technology' remains the main approach of research and development programmes.

The first step in offering support for farmer experimentation in finding solutions to problems is to identify the problems themselves. Although this thesis did not directly assess the degree of involvement of different organisations in promoting farmer-based research, examining how these organisations perceive farmer problems in relation to the farmers' own perceptions (see 8.1), can shed light on whether their orientation is participatory or 'transfer-of-technology', and in the latter case, what can be done to shift the orientation towards participation.

During the 1980s and early 1990s, the EEC sponsored a programme of research and training activities under the heading of JPERDP (see 2.3). Phase II of the programme was intended to be development-oriented and include practical experimentation amongst selected communities (Phillips-Howard, 1992b). Four communities were chosen to be involved in a farming project, amongst which were the Delimi Langalanga farmers (who in the report are referred to as Delimi River-Yelwa farmers—from the name of the village where the majority live). The farmers were encouraged to form into associations so as to find common solutions to their problems. The Delimi farmers formed the Yelwa Farmers Association. Farmers had identified as priorities, obtaining IF, pump-engines and seeds. Accordingly the JPERDP identified subsidised sources of these inputs and its key role was in facilitating dialogue with PADP. For the most part, the trials were quite successful and apart from a few disruptions caused by individual self-interest, they increased the capacity of the associations to mobilise themselves towards greater use of their resources. Certainly, in the case of the Yelwa farmers, the intervention of JPERDP helped set up friendly relations with PADP, which gave the association more autonomy and stimulation to look for sources of subsidised IF and other inputs (Phillips-Howard, 1992b).

Interviews with the farmers in 2000-2001 (8.1) indicated that farmers felt that PADP was not supporting them adequately, to the extent that a number of individuals were very bitter and angry, especially over a World Bank sponsored irrigation project, which PADP was administering. This suggests that, since the JPERDP, there has been a breakdown in communication, and to understand to what extent this has happened, the respective positions of the farmers and PADP must be analysed and compared, before any solutions can be advanced.

In order to do this, a summary of the role of PADP and, in particular, its involvement in the World Bank sponsored irrigation project, will be presented. This will be followed by: a summary of PADP's concerns and on-going and future projects, to gain an idea of what problems PADP think are important; a case study on the World Bank project, that presents farmers' and PADP's assessment of the project; and a review of the extent to which there is a mismatch between farmers' and PADP's priorities and suggestions for the potential ways to alleviate this and promote effective participatory research. The case study information was obtained in three ways: during a formal visit to PADP, when three representatives were interviewed about the role of the organisation and in particular their involvement with dry-season vegetable farmers (to preserve their anonymity their names and positions are not provided); from an internal report on the National Fadama Development Facility, provided by PADP (PADP/NADP, 1998); and from interviews with the farmers (8.1). These topics will be covered in sections 8.2.1 to 8.2.4.

8.2.1 Role of PADP

PADP was set up in 1987, when the Agricultural Development Programme went State-wide, to give formal support to the farming activity on the Plateau. PADP primarily offers advice on all farming problems through the activity of extension agents. Extension agents are continuously trained through the Monthly Technology Review Meeting (MTRW) and then they go into the field, observe problems and try to address them. In 1992, PADP adopted a Unified Agricultural Extension System (UAES) that gives prominence to non-crop sectors (livestock, fisheries and agro-forestry), while also taking into consideration gender-specific issues and agro-processing constraints. The evaluation of improved technologies for vegetable production has particularly been made possible with the establishment of a 'Fadama Unit' within the PADP. Furthermore, PADP organises the dry-season farmers through the FUA, so that the farmers can obtain subsidised materials from the Plateau State government. The organisation also provides good quality seeds, agro-chemicals and water pumps.

In 1996, the organisation produced a technical notebook entitled 'Package of crop production practices for Plateau State' (Cheema *et al.*, 1996). This contains crop recommendations based on the results of technologies developed by the National Agricultural Research Institutes (NARIs) and evaluated as On-Farm Adaptive Research (OFAR) by PADP and at the MTRW. The purpose of this was to provide a reference and a guide to extension workers and farmers. It contains information on a wide variety of wet and dry season crops (of the latter it provides information for growing tomato, cabbage, carrot, onion, pepper and lettuce).

8.2.1.1 The work of extension agents

Extension agents are trained to provide advice to farmers and to bring in new ideas and information. To facilitate the diffusion of their work, a link with the farmers was created through the FUAs. Unfortunately, their impact is limited by the low numbers of operators (one extension agent for about 1000 farmers) and by their lack of mobility. In the past, the agents had been provided with motorised transport (usually motorbikes) but now many of the vehicles are out of order, there is no money for repairs and even the few that are operative cannot be used because of the petrol scarcity. Originally, the idea had been that one extension agent would be assigned to a cell, which would be made up of one or two districts. Two or three districts would make up a block and blocks would be aggregated into zonal offices. Each extension agent would visit all the villages in his cell within two weeks and then start over. The zonal offices are now so hard-pressed that they are purchasing bikes as transport rather than motorbikes but, of course, now the extension agent cannot reach all the villages within two weeks and may be forced to operate only within his own locality.

8.2.1.2 The National Fadama Development Facility

PADP were managing an irrigation scheme funded by the World Bank. This was the National Fadama Development Facility (NFDF) and official information about this was drawn from the 1998 Internal Implementation Completion Report of the National Fadama Development Facility (PADP/NADP, 1998), as well as the interviews with the PADP representatives in 2001. The NFDF covered the whole of Plateau State.

The NFDF was set up by loan No. 3451-UNI. This loan was approved in February 1992 and made effective in December 1994. At the time of writing the 1998 Internal Implementation Completion Report by Plateau and Nassarawa Agricultural Development Programmes (PADP/NADP), the project was expected to close in September 1998. Co-financing of the project was provided by the World Bank (68%), the Federal Government of Nigeria (4%), Plateau/Nassarawa State Governments (PLSG/NASG) (4%) and the farmers (24%). The project was, in fact, still running in 2001, as interviews with PADP representatives disclosed.

The overall objective of the project was "*To contribute to food security and poverty alleviation by increasing agricultural production and income of small holders*" (PADP/NADP, 1998, p. 1). It sought to do this by developing small-scale irrigation in the *fadama* areas by introducing petrol driven irrigation pumps; introducing various types of drilling technologies to tap shallow ground water; organising farmers into co-operative groups (FUAs) to ensure the sustainability of the project, irrigation management, cost recovery and better access to credit, marketing and other services; installing 1450 shallow tube-wells by drilling and wash-boring[1] over a period of three years, constructing fadama infrastructures (3km of fadama roads, 10km access roads and 10 culverts); procuring and distributing 1450 irrigation pumps for the development of 1450ha of fadama land.

In 2001, the whole package of a wash-bore and a pump engine could be provided for a total cost of 30,000 Naira with a down-payment of 18,000 Naira. The rest of the money would have to be paid within a year. A group of farmers (about 20 people) would be able to afford the down-payment by pooling their yearly subscription fees to FUA. As the Plateau is rich in surface waters, PADP was actually providing the pump engines to the farmers, without the wash-boring, for a total cost of 28,000 Naira. On the whole, the project was running quite smoothly as PADP was not experiencing problems with farmers defaulting from the rest of the payment for the pumps.

8.2.2 PADP's research concerns

Research and observation by PADP agents has brought certain problems to their notice. PADP's first concern is about the environmental impacts of '*fadama*' farming as they have noted a rising and indiscriminate use of agro-chemicals (both pesticides and IF), which they fear could be damaging to the environment. Pesticides, in particular, are sold on the market by unqualified agents, who are not able to give correct advice to the buyers. They are aware that farmers have considerable problems with pest damage.

Their second concern involves the over-production of vegetables that is resulting in a loss of profit by the farmers as prices drop drastically.

[1] Wash-boring is a jetting technique that uses a high velocity stream of water to bore the tubewell.

Their third worry is that seeds are imported through channels other than the official one, the Plateau Quarantine Programme. So, while PADP seeds are tested and reliable, other seeds on the market may actually be expired and may not germinate.

Their fourth apprehension is about soil fertility. PADP have been trying to establish a soil laboratory to test samples and make accurate IF recommendations but government programmes require a long time before they are implemented. They believe that farmers are probably already aware of declining soil fertility through declining yield. Farmers receive subsidised IF but it is in very small amounts and is not enough. They are trying to encourage farmers to go into 'organic' agriculture (i.e. using organic fertilisers). They believe that farmers are beginning to perceive the benefits of using manure. Poultry manure in particular is readily available because of the poultry production boom of the last three-four years.

8.2.2.1 On-going and future research projects

PADP affirmed that they thought that the farmers irrigated too frequently and would damage their farms. They were conducting trials to prove that frequency of irrigation could be reduced, although they had found that during the Harmattan season the 5-7 day interval, which they thought viable, was too long. They were suggesting compromises to the farmers, asking them to dig under the topsoil and test how moist or dry the soil was before deciding to irrigate.

They were also involved in trials for pest control. They were currently involved in setting up a trial with a chemical that contained Neem extract.

They planned to run a soil testing programme that would involve 100 farmers on the Plateau (50 in the north and 50 in the south) to make targeted IF recommendations, as the current ones were too broad (NPK 120:60:60 for the northern zone, NPK 90:45:45 for the southern zone). They were not able to start the programme immediately because they lacked the funding for it.

8.2.3 A case study problem: NFDF

One of the major sources of dissatisfaction amongst the farmers was the controversy surrounding the distribution of the pump engines under the World Bank sponsored NFDF irrigation project. The aim and details of this project have been provided in 8.2.1.2. The next two sub-sections summarise what the farmers thought the project was trying to achieve and what their complaints centred on, and PADP's views on the varying degree of success of the project.

8.2.3.1 The farmers' story

1. The farmers believed that PADP's role in administering the NFDF project was to distribute the subsidised pump engines to *individual* farmers, through the mediation of FUA.
2. They had been told that the down-payment for the pump engine was 18,000 Naira and, within a year, they had to complete payment up to a total of 30,000 Naira[2]. They stated that they could not raise such a large sum of money, particularly during the year, before harvest.
3. There was a widespread belief that, in neighbouring Bauchi State, pump engines were being distributed for a down-payment of 5,000 Naira. This view was also held by a reliable key informant.
4. Some farmers believed that the down-payment in Plateau State was so high because PADP were worried about being held responsible by the World Bank if a farmer failed to finish paying for the pump.
5. Farmers were aware that PADP had many pump engines in store, but were not distributing them to farming communities.
6. Very few pump engines had been distributed in the Delimi Langalanga area. Since the beginning of the project, only one batch of 8 pump engines had been distributed (in a community that counts more than 50 farmers).
7. Some held the view that there was corruption within PADP. Although they admitted that in principle the organisation was set up to help them, in practice the officials were only interested in misappropriating funds and resources. They explained that government officials claimed to be farmers (because they owned a small plot of land somewhere), and could obtain farming inputs that were subsidised by the World Bank, which they then re-sold on the black market. One farmer claimed that this had happened with the pump engines, but that the individuals responsible for this had been found out.
8. Farmers had not received extension visits since the introduction of IF (in the 1970s).

8.2.3.2 PADP's story

1. PADP were clear that the farmers would be able to purchase the package of a pump engine and a wash-bore as a *group* (of 20 or so farmers), by using the yearly subscription fee to FUA.
2. The down-payment was 18,000 Naira, the total payment, without a wash-bore, was 28,000 Naira.

[2] On the open market a 2-inch Robin pump engine cost 29,000 Naira and the 2-inch Honda pump engine cost 31,500 Naira (prices could be slightly inflated as no attempt at bargaining was made). Quotes from various farmers ranged from 27,000 Naira for a 2-inch pump engine to 37,000 Naira for a 3-inch pump engine

3. PADP were not having any problems with farmers defaulting from further payment. On the whole, the project was running smoothly[3].

4. PADP stressed that, although the World Bank's performance was satisfactory, funding from the Federal and State government was not: "*During project implementation, counterpart funding was grossly inadequate as well as being untimely.*" (PADP/NADP, 1998, p. 16). "*FGN[4] should match words with action by ensuring timely releases of their subventions.*" (PADP/NADP, 1998, p. 16).

5. PADP complained that: "*The centralization of facility funds and managed by FACU[5] created bottle-necks in project implementation. For future projects, each project should be allowed to manage its resources by direct access to the Banks which will facilitate project implementation.*" (PADP/NADP, 1998, p.16).

6. PADP also commented on the inapplicability of the pump engine and wash bore package to the environmental conditions of Plateau State: "*The technology package (pump and wash bore) is not appropriate in the prevailing situation where there is abundant availability of surface water. Future projects should focus on ensuring effective use of these surface waters*" (PADP/NADP, 1998, p.16). They had found that those areas where the aquifer study showed that a wash-bore had high potential did not overlap with existing irrigated agricultural activity, so the project was not viable

7. They observed that the response of the farmers was negative to the extent that: "*The washbore technology was not readily acceptable by farmers due to the abundant surface water available, so problems like removal and blocking of washbores by the communities and nomadic Fulanis were initially encountered. We will expect that future project design should take cognisance of peculiarities of each participating state*" (PADP/NADP, 1998, p.15-16).

8. The Fadama Infrastructural Development achieved most of its objectives as 85% of the target access roads (8.5 km) and 50% of the fadama roads (1.5 km) were built (PADP/NADP, 1998).

9. The formation of FUAs was also very successful, as in 1998, 1200 FUAs had been formed, 388 of which had been certified (PADP/NADP, 1998).

10. PADP's performance in pump procurement was highly successful. Out of 1450 pump engines, 1100 pump engines were received into store and they were awaiting delivery of a further 350 (PADP/NADP, 1998).

[3] The information in points 1 to 4 was obtained from interviews in 2001.

[4] Federal Government of Nigeria.

[5] Federal Agricultural Co-ordinating Unit

11. In regards to the impacts on farmers, they stated that: "*The implementation of Fadama facility has positively affected the socio-economic life of the farmers. Though the effects cannot readily be quantified, general observation indicate that the standard of living of the target population has improved significantly due to increased income resulting from incremental production of dry season crops over the years*" (PADP/NADP, 1998, p.2), and "*More farmers are now engaged in dry season farming due to its high economic return over that of rain-fed agriculture. As a result of this, the area under fadama cultivation and the production has continued to be on the increase*" (PADP/NADP, 1998, p.3).

12. In relation to the distribution of the pump engines between 1995 and 1998, PADP stated that: "*The poor performance of washbore technology affected pump distribution as the two are to be delivered to farmers as a package. The specificity of the project design which was to address the peculiarities of the core beneficiary states made it impossible for the facility states to change the focus of the project.*" (PADP/NADP, 1998, p.7). Table IV (PADP/NADP, 1998, p.21-24) presented data on the progress of the NFDF, which showed that between 1995 and 1998, PADP had installed zero tubewells by washboring out of the target 1450, and consequently none of the target 1450ha of land had been developed. In the same years, in terms of extension, PADP had employed 239 extension agents (62% of the target number), had achieved 97,642 visits (51% of the target), had broadcast 143 TV farming programmes (63%), 209 radio programmes (84%) and carried out 53 demonstrations (50%).

8.2.4 Discussion

The interviews with PADP (8.2.2 and 8.2.2.1) have shown that the organisation has identified some very important farming issues, notably the indiscriminate use of agro-chemicals (pesticides and chemical fertilisers), which could have some serious implication for the environment, the over-production of vegetable produce, and the problem of soil fertility maintenance. They also believed that farmers were irrigating too frequently, and they were taking action by running trials to try and reduce the frequency of irrigation. In terms of the problem of pest management they were involved in trials with a chemical that contained Neem extract, and concerning the problem of soil fertility, they envisaged a soil testing programme across the Plateau, but this was awaiting funding. They also planned to encourage farmers into using organic inputs, to decrease dependency on IF.

8.2.4.1 Overlap between PADP and farmers' concerns

To a certain extent, there is overlap between PADP and farmers' concerns. Farmers were concerned about the problem of heavy pest infestation (which was leading them to pesticide over-use) and they would have welcomed research into the problem. Although farmers in Delimi did not identify pests as a major problem, possibly because they did not specialise in crops that were susceptible to pests, during visits to other locations (Rayfield, Anglo-Jos and Barakin Ladi), farmers were eager for help with pest control and repeatedly asked for research in this area. PADP were responding to this concern with their trials. Farmers were also aware that there was a problem with over-production of crops, which led to a loss in profit, but whereas they identified refrigeration facilities or food-processing facilities (such as a tomato canning factory) as solutions, PADP were not involved in any research or project that could provide a solution.

8.2.4.2 Mismatch between PADP and farmers' concerns

The problem of soil fertility, though, shows that there can be mismatches between PADP and the farmers' viewpoints. PADP's concern with the over-use of IF, led them to affirm that they were encouraging farmers to use organic inputs, particularly poultry manure, as there had been a boom in the poultry business in the previous years. However, PADP did not seem to be aware that farmers would be willing to use poultry manure (as it was part of their traditional soil fertility management strategy—see 5.1 and 5.2), if they were not constrained by cost (both of the manure itself and the transportation costs) and scarcity. This situation has probably been caused by the presence of very few extension agents in the field (8.2.1.1 and point 8 in 8.2.3.1) poor funding of PADP, and the swift expansion of DSIVP, which would result in the farmers using up new sources of inputs very rapidly (see 5.2.3 for a full account of the decline in the use of organic inputs).

PADP's concerns about the quality of the inputs with which the farmers are working are also valid. They explained that they stocked good quality inputs, so farmers should purchase from them. Farmers readily acknowledged that PADP's products were of good quality, but gave various reasons for not purchasing them. The seeds provided by PADP are more expensive than those found on the market and, frequently, PADP do not have the required seeds in stock. Farmers are aware that market sellers can adulterate the pesticides, but they simply cannot afford to buy in large quantities. Even a litre bottle of Gamalin 20 is beyond their purchasing power so they resort to using the market, where the sellers break down the litre bottle into approximately 300ml quantities. It is, of course, relatively more costly but small-scale farmers can only afford to buy in small amounts. There is also the additional discouragement of the location of PADP. The organisation is located off the Bauchi Road, not far from the University of Jos. This is an easily accessible location for town dwellers but not for farmers, who work on the fringe of the town or in other locations on the Plateau. Unless the farmer is going to acquire a large supply of inputs, the trip is not worth the time and the travel money. The farmer is more likely to go to a local market, where he can sell some produce, and at the same time buy IF, seeds or pesticides. This is particularly true for farmers who work on the Plateau, far from Jos.

The only PADP depot is the one in Jos, and, as one farmer in Barakin Ladi commented, the travelling distance to Jos outweighs any benefits attached to purchasing from PADP.

The case study on the NFDF is a good example of where poor communication can result in alienation and misunderstanding. The farmers clearly were not informed or did not understand the restrictions imposed by the World Bank. They knew that PADP had numerous pumps in store, they were aware that pumps were being distributed in Bauchi State, and they felt 'cheated', because the pumps were being held back. They needed to be made aware of *why* this was occurring. On their part, PADP were not fully attuned to the undercurrents of malcontent running through the farmers, and their necessities. One representative concluded that the project was "*running smoothly, as they were not suffering of the problem of farmers defaulting from the rest of the payment*". This indicates that PADP were not aware that their limited distribution of pump engines (for valid reasons) was causing resentment.

8.2.4.3 Facts that PADP should be aware of

Similarly, PADP need to be conscious of the fact that farmers prefer to have one pump engine each and, at the most one pump engine can support three farmers, maybe four, but no more. This is because the survey data (4.7.1) shows that 63% of farmers irrigate twice a week, 29% three times a week, 4% two to three times a week, 2% once a week and 2% three to four times a week. Although PADP worried that farmers were irrigating too frequently, discussions with the farmers showed that they were conscious of differences in watering requirement between soil types, which suggests that they have observed, through trials, what the ideal watering interval is. Considering the costliness and effort spent in acquiring petrol for the pump engine, it seems highly unlikely that farmers would irrigate more frequently than they would have to. Therefore, if irrigation occurs on average twice a week, it is evident that having even four farmers to one pump engine would require a rigorous and strict calendar of irrigation, and 20 would definitely be impossible.

Furthermore, PADP should take note that the down-payment of 18,000 Naira is excessive, and limits the acquisition of a pump engine to a large-scale farmer, who can rely on external sources of money. A small-scale farmer cannot raise the partial payment of 18,000 Naira, anymore than he can raise the full payment of 28,000.

On the other hand, the NFDF has resulted in some positive outcomes. The creation of FUAs is, undoubtedly, important, as it has organised the farmers into legitimate pressure groups. The most significant enterprise of the over-arching FUA has been the creation of a farmer-controlled market (Appendix C), which was launched 5 May 2001[6].

8.2.4.4 Conclusions and recommendations

In conclusion, this analysis has shown that there is a sense of dissatisfaction amongst farmers about the role played by PADP, that was partly caused by misunderstanding on the part of the farmers, and partly by the lack of dialogue (on an equal footing) between farmers and PADP. PADP have many valid concerns and have various plans for addressing them. Unfortunately, they suffer from a lack of funding, which prevents them from employing a sufficient number of (mobile) extension agents, and to have the laboratory facilities necessary for their plans. Nevertheless, there is space for improvement, even with limited resources. The following suggestions are made:

1. The thesis has shown at numerous stages that farmers are very skilful and knowledgeable in a variety of issues. PADP can usefully use this information to identify areas that require intervention and research that is beyond the farmers' expertise. Farming problems are often quite intricate and farmers may have a better understanding of which solutions can work and which cannot, but they may not have the technical understanding or the resources to solve the problem by themselves. This is where an organisation such as PADP can intervene.
2. Although it is recognised that PADP have few extension agents operating in the field, their work could be optimised if they engaged in in-depth interviewing with both small-scale and large-scale farmers, to learn about what farmers are doing, what their constraints are, and what they do to try and overcome them (especially as the farmers have common problems). At this point, PADP could identify constraints that farmers could not overcome alone, and they could use their resources to find a partway solution. It may not be the 'perfect' solution but while PADP lack the funding to bring about substantial changes, they can help farmers to find their own solutions. For example, PADP identified that the compound fertilisers produced on the Plateau are of the wrong formula for the soils there and planned a soil-testing programme to make more targeted recommendations. This was conditional on obtaining funding from the Federal Government. This thesis has shown that farmers were already aware of the limitations of the IF, and were responding by mixing different type of IF (point 4 in 5.1.1), and using manure and ash. PADP could intervene by discovering why certain IF considered useful by the farmers (e.g. DAP), were no longer available, and encourage local IF manufacturing companies to start producing it. Or, they could help identify sources of manure and ash, and liase with the producers to encourage them to sell to

[6] As research for the thesis finished 10 May 2001, and no follow-up visits have been possible since then, due to political unrest, it is not known whether this market has been successful.

the farmers at a reasonable price. The point is that PADP should help the farmers to help themselves.

3. PADP should focus on small-scale farmers. There was the feeling amongst the small-scale farmers that the few existing government initiatives involved large-scale farmers only. This is probably true, as the Nigerian society is strongly hierarchical, as even in Delimi, it was first necessary to get the consent of the head of the farmers, before the other farmers could be interviewed. PADP should make a concerted effort to speak to small-scale farmers, in addition to large-scale farmers.

4. PADP can make use of the FUAs. To some degree, extension agents do not need to go into the field, to pass on information. The leaders of FUA can be used to make sure that information trickles down to the remainder of the farmers in each farming area. PADP can facilitate this by organising monthly meetings in each farming area that is covered by one FUA. One extension agent could be assigned to each FUA, so instead of visiting each individual farmer, the agent would meet a group of farmers. The meeting should be used as a forum of exchange, with farmers discussing their problems and advancing their solutions. The extension agent would have to be trained in participatory techniques, so that he could fruitfully manage the meeting, and get farmers to share their successes, identify their problems and propose action. In time, the farmers would be able to solve most of their problems independently, and PADP would have to find solutions to the remainder.

5. The solutions proposed above would take time, and some degree of training of the extension agents, before they could be used. In the short-term, however, it is strongly recommended that PADP take steps towards resolving the controversy surrounding the issue of the World Bank irrigation project. This could be done by writing directly to the World Bank (multiple letters, to more than one person, if necessary) and asking for greater flexibility so as to meet the particular irrigation circumstances of the Plateau; by greater dialogue with the leaders of the farmers, so as to explain the restrictions of the project (showing them evidence on paper, if necessary); and meeting the farmers half-way, by finding a way to reduce the down-payment from 18,000 Naira to a more manageable sum.

6. Additionally, PADP could start liasing with local banks to allow farmers access to credit facilities. Farmers identified finance as their major constraint, and if farmers had access to some credit at the beginning of the farming season particularly, and in special circumstances, such as when they need to purchase a new pump engine, many difficulties would be eased.

7. Finally, concerning provision of good quality inputs, PADP could arrange the sale of small quantities of expensive products, to reduce cost to farmers. For example, large bottles of pesticides could be split into smaller, more manageable quantities, and PADP's involvement would prevent adulteration that can instead occur with market sellers.

8.3 HOW IMPORTANT IS SOIL FERTILITY MANAGEMENT?

Section 8.1 has presented general farming problems as perceived by farmers, and it is apparent that farmers have pressing concerns, that threaten to put them out of business in the short-term. Soil fertility is a long-term problem and, as such, it was not ranked very highly. Or rather, farmers did prioritise obtaining IF, but this is not equivalent to maintaining soil fertility in the long term.

8.3.1 Linking the thesis' conclusions to farmers' concerns

The analyses carried out on the case study farms (Chapter 6), coupled with general information on SFM practices (Chapter 5), indicate that although most farmers are meeting crop nutrient demand with IF, there is a trend of declining organic matter. Already farmers are complaining that organic inputs are costly and scarce. Should DSIVP continue to expand, this trend is likely to be accelerated. The decline in the use of ash is also worrying, because ash counters soil acidity. As Alexander (1996) has concluded, the reduction of organic amendments (both manure and ash) in favour of IF, could lead to soil acidification, a reduction in the structural stability of the soil and a decline in the overall nutrient status (as IF do not supply all nutrients required by the crops).

However, it is recognised that, currently, farmers have too many short-term concerns to enable them to be receptive to the problem of soil fertility. Delimi farmers (like farmers everywhere) are driven by market forces, by the need to produce competitively. They require IF for fast growth, a pump engine to irrigate, petrol to operate the pump engine, and a market for their produce. Farmers seem to be satisfied by their yields, but many of the small-scale farmers were barely recouping their expenses. PADP have rightly pointed out that this is caused by over-production. Farmers flood the market with the same type of produce, and prices drop drastically.

8.3.2 Improving farmers' situation

There is much that can be done to improve the situation: firstly, by providing farmers with access to credit facilities. The farmers identified the lack of capital as their major problem: in this they are correct. With sufficient capital flow, the farmers can improve the management of their business, and this, in turn, can have a positive impact on soil fertility. The most successful farmers appeared to be those who had other businesses that could provide the capital to operate the farm until harvest. Sa and Au's farms are good examples. Sa was involved in several different activities, which provided the cash to tend his farm. At the beginning of the season, he did not have difficulties in obtaining the necessary inputs, seeds, fertiliser and petrol. He had a large farm and could afford to purchase fertiliser in 50kg bags, which, in the long run, reduced costs (the farmers could purchase fertiliser in *mudus*, rather than 50kg bags, but this was relatively more expensive). The fact that he had the capital available meant he could purchase the fertiliser he wanted, even the more expensive types (e.g. super-phosphate). In terms of soil fertility, this had resulted in the accumulation of P in the soil. At the end of the season, Sa was in a position to hire a truck to convey his produce to Port Harcourt, where he would obtain a better profit than if he traded through local middlemen. This allowed him to recover his expenses. Au operated on a similar basis. Au was a successful trader, and left the management of the farm to a relative. With the money from his business, he could purchase produce from his small-scale neighbours, and sell this, and his own crops, directly in Port Harcourt, at a considerable profit. In this way, large-scale businessmen/farmers will continue making a profit and expand.

Full-time farmers are not successful in the same degree, even if they farm large tracts of land. They are vulnerable, because they do not have capital and contacts in time of need. For example, Ab rented a very large farm, but he had difficulties. His pump engine had broken down and he could not afford the 18,000 Naira down-payment required for a World Bank sponsored pump. He was surviving by borrowing a neighbour's pump engine. He hired labour but not enough to clear all his land at the beginning of the season. He progressively cleared land throughout the season, producing fewer crops than he could have. He could not afford to market his produce directly in southern markets and, indeed, he sold part of his crops to Au. If Ab had had access to credit, he would have been in a better position to produce more and get better returns. Still, he was surviving because he had access to a neighbour's pump. Another man, who was in the same predicament, had farmed during the wet season but was eventually forced to abandon dry-season farming.

Access to credit facilities, which could be negotiated through collaboration between PADP, FUA and local banks, would improve the situation of farmers (small-scale ones, in particular). Farmers could solve many problems autonomously, without expecting government support. If short-term problems are removed, farmers can be more receptive of long-term problems, such as soil fertility.

It is cautioned, though, that the establishment of credit facilities needs to be considered carefully, in the light of experiences in other low-income countries. Although equitable (in terms of women's involvement) and sustainable (in terms of the livelihoods of the beneficiaries and the financial viability for the service providing institutions) micro-lending is increasingly seen as a new paradigm for 21st century economic and social development, and is being upheld by many bilateral and multilateral development agencies (who incorporate some form of credit lending into their programmes, and are keen to push non-governmental and private voluntary organisations into the function of credit delivery) (Rahman, 1999), several authors are calling for caution in focusing narrowly on credit operations (Ahmed and Chowdhury, 2001).

Adams and Von Pischke (1992) feel that current micro-enterprise programs share many similarities with small farmer credit programs of the past, and so they are likely to incur the same problems. It is their opinion that small farmer credit programs have, overall, been unsuccessful. In their own words: "*Most of these programs were transitory and reached only a small percentage of the farmers targeted, who were in turn a minority of the rural population. These programs were unsustainable because they were expensive, collected too little revenue, depended too heavily on outside funding, and often suffered serious default problems*"(p.1465). They believe that the micro-enterprise programs are set to end up as unsuccessfully as the small farmer credit programs, and they conclude that, in their opinion, debt is not an effective tool to help most poor people enhance their economic condition, be they operators of small farms, micro-enterprises or poor women.

Other authors are less negative about credit facilities as a whole, but do warn that they are not the global solution to poverty. This has been illustrated by the experiences in Bangladesh. The micro-credit delivery system was pioneered by the Grameen Bank in rural Bangladesh. The programmatic success of the Bank, and the accreditation of this success by a number of impact and academic studies, has often hidden from view how, despite the Bank's success in delivering loans to poor women and bringing socio-economic changes to these households, many borrowers become vulnerable and trapped by the system (Rahman, 1999). For example, at the level of the grass root operation, bank workers and peer group members put intense pressure for timely repayment on the borrowers, rather than work on raising collective responsibility and borrower empowerment, as originally planned. This means that many borrowers meet their repayment deadlines by loan recycling (i.e. paying off previous loans by acquiring new ones).

Mosley and Hulme (1998) reported on a research project that investigated the impact of 13 microfinance institutions in seven developing countries. They showed that there was a positive, curvilinear relationship between borrower income as a percentage of the poverty line income and the increase in borrower household income (as a percentage of the control group average increase). In other words, there was a tradeoff: lenders could either, focus their lending on the poorest, and accept a relatively low total impact on household income, or, they could achieve a higher impact by focusing on the not-so-poor. In some cases, for households a long way below the poverty line, the average loan impact could actually be negative. This led them to conclude that, although the micro-credit model worked for the not-so-poor, a different model of lending would be required for the poorest, based perhaps on the provision of savings facilities, simple insurance facilities, and small consumption loans with flexible repayment periods. All this, so that, in time, the very poor would gradually reduce their income vulnerability and move from borrowing for consumption to riskier investments in working capital, hiring of extra-family labour, and ultimately fixed capital.

It is important that PADP and FUA should take into consideration these lessons, acknowledging the differences between countries, before attempting to implement credit facilities on the Jos Plateau. For example, although the practice of focusing on lending to women by many credit lending facilities, such as the Grameen Bank in Bangladesh[7], would not be suitable for all-male, Islamic communities on the Plateau, the wider lesson that farmers near or below the poverty line would benefit very little from credit facilities could be applicable. Furthermore, given that farmers seemed reluctant to work co-operatively by pooling resources, even just to buy cheaper, bulk amounts of fertilisers (because of a widespread lack of trust), there is a question of whether using peer group pressure to ensure regular repayment would be appropriate. All these issues must be considered carefully, before any action is taken.

Additionally, it must be said that not all problems can automatically be solved through credit facilities. For example, if the decline in the use of organic inputs is dependent on a cost constraint, the situation can be ameliorated. Yet, if it is caused by scarcity, then the situation requires considerable government intervention. PADP needs to investigate, in the first instance, whether there are untapped sources of organic inputs and negotiate access to these sources on behalf of the farmers. Urban refuse is an important source of organic material, but there are risks and problems attached to using this amendment. Chapter 7 has discussed this problem in detail. In brief, any solution (an incinerator plant, or a large-scale composting facility) will require careful management, goodwill, and substantial funding from the government.

An important step to take to improve the conditions of farmers on the Plateau, is to facilitate the flow of information between the 'scientists' (represented by PADP and extension agents) and the 'practitioners' (the farmers). Extension agents need to be trained to be receptive to what farmers are demanding, and also they need to acquire an understanding of farmers' knowledge. On their part, farmers need some degree of education to be receptive to problems that they cannot readily perceive. For example, farmers had little knowledge about pest management (and did not understand the health hazards of applying pesticides without

[7] Since the 1980s, the Grameen Bank has focused primarily on women, even though prior to that there were both women and men's groups. The official explanation for the shift in focus was that it was preferable to lend to women, because they tended to invest more in family welfare than men did, and because it was also a way for poor women to achieve socio-economic empowerment within society. In reality, the change occurred because the Bank was experiencing increasing repayment problems in the male centres. Thus, the heavier recruitment of women would make the Bank's goal of investment and recovery of loans easier to achieve (Rahman, 1999).

protective clothing), the environmental consequences of over-using agro-chemicals, and the health risks attached to using urban waste ash. This means that even if they are told about these threats, they may not take precautionary measures. Farmers who have not received any formal schooling, could be given a background on basic agricultural principles and problems, through the work of PADP. As already proposed in points 4 and 5 in section 8.2.4, PADP could collaborate with FUA to organise forums in each farming area. The forums would serve as a teaching class (the extension agent could hold simple classes for a short period at the beginning of each meeting), as a debating session (an exchange of ideas, problems and potential solutions amongst farmers), and as a learning experience (for the extension agent).

8.3.3 Conclusions

In conclusion, although soil degradation does not represent an immediate threat, if DSIVP continues to expand and farmers continue reducing organic inputs, it will become a problem in the not-so-distant future. Furthermore, it will not be the only environmental problem. Pollution caused by the over-use of agro-chemicals, and pressure on water resources (Porter *et al.*, 2002) may also become significant. It is acknowledged, though, that farmers need to resolve their short-term concerns, before they can be convinced to address longer-term issues. This is a task for the Federal Government of Nigeria (FGN). PADP have identified many valid problems, but they lack the resources to carry through many of their projects. FGN must release additional resources if they hope to maintain production on the Plateau, but it is also strongly recommended that its extension service first be trained in the latest participatory techniques, for optimal management of these resources.

9 CONCLUSIONS

This thesis has employed research tools from both the natural and the social sciences. It is important to cut across the boundaries of different disciplines, particularly in agricultural research. Viewing the same problem from different angles heightens the understanding of the problem and immediately throws into light the fact that a problem can never be considered in isolation. A problem can be addressed from a technical perspective but if an influential economic factor is ignored, the solution will not be effective. Additionally, problems can be interconnected, so that the resolution of one can aggravate the other. Blending these two different approaches has hopefully provided a more complete picture of soil fertility management strategies in DSIVP, in peri-urban areas around Jos.

9.1 MAIN CONCLUSIONS

The next four sections (9.1.1 to 9.1.4) summarise the critical findings of the thesis in relation to each major aim (2.7).

9.1.1 Soil fertility management strategies (aim 1)

The first aim of the thesis was to collect information not only on current fertilisation practices, but also on the rationale behind them. It also sought to examine likely future trends in fertilisation practices.

9.1.1.1 Methodological considerations

1. There were problems in accessing and understanding knowledge, apart from the fact that knowledge is 'patchy'. The language could be a barrier to understanding farmers' statements but in addition there was the fact that farmers possess informal (or tacit) knowledge, and do not communicate with formal knowledge (5.2.2.1). There was also a discrepancy between what farmers wanted to do and what they could actually do. Thus, what they *said* they would do, often differed from what they actually *did* do (5.2.2.2).
2. Information changed depending on what method was used to access it. During the surveys, farmers could give out the impression of having superficial knowledge about an issue, but when this was followed up with an interview it emerged that farmers' had much more in-depth knowledge than was initially thought (5.2.2). Furthermore, observation complemented the information obtained during the interviews, as quite often farmers did not put into practice what they stated they would do (6.3.3).

9.1.1.2 Key findings about current SFM practices

1. Farmers strongly advocated the integration of inorganic and organic amendments, claiming that each material played a particular role in the maintenance of soil fertility. This idea is, in effect, 'integrated plant nutrition', a concept that is increasingly popular in 'scientific' agricultural research (5.2.1).

2. Most farmers had no formal understanding of the composition of IF, however, through empirical means, they had learnt which combinations were effective for their land (5.2.1).

3. There were almost as many SFM strategies as there were farmers (5.2.1).

4. The use of organic inputs had declined in the study area. Farmers in Delimi appeared to have ceased using manure almost completely, and their use of ash was, on the whole, restricted to farm waste ash. Farmers in Rayfield were still acquiring poultry manure and ash, which they used in combination, but complained that they were forced to reduce the amounts they purchased because of high cost and scarcity. Cattle manure was hardly available (5.2.3).

5. Consumption patterns of IF in Delimi and Rayfield are equivalent to those of a developed country. In fact, it appears that many farmers are over-using IF, although one likely reason is that as IF are of the wrong formula for Plateau soils (Alexander and Kidd, 2000), the necessity of applying sufficient amounts of one nutrient (such as N), may result in the over-application of another (5.2.4).

9.1.1.3 Comparison of SFM practices to those recorded in the 1990s

1. The basic soil fertility management strategy has not changed since the 1990s. The farmers advocate the use of a combination of IF, manure and ash, as they did in 2001 (5.3).

2. In 1990, there was heavy reliance on organic amendments because of the scarcity of IF. This contrasts to the current situation, where, despite complaints about cost and scarcity of fertilisers, farmers prioritised obtaining IF over organic amendments. The situation seems to have affected the transmission of knowledge, as in 1990 farmers were very communicative about organic fertilisers, but in 2001 they had to be questioned specifically before they would discuss organic inputs, especially manure (5.1.1.2 and 5.3).

3. Certain IF, such as CAN and DAP, have disappeared from the market since 1990. Farmers complained that they had found those particular types very useful, but they could no longer find them (5.3).

9.1.1.4 The rationale behind SFM practices

1. Farmers are very knowledgeable about soil fertility management practices, as demonstrated by the interviews in Delimi and Rayfield (5.1.1 and 5.1.2).

2. Not all farmers share a uniform body of knowledge. Some knowledge was common to all farmers, but certain individuals were more knowledgeable than others (5.2.2.1). Furthermore, there were differences between locations, as some themes emerged in Delimi but not Rayfield, and *vice versa* (5.2.2.1). This, in itself, is not a remarkable finding, as other researchers have come to similar conclusions in different areas (2.4).

3. Farmers' empirical observations are an effective means of gaining knowledge. A good example of farmers' empirically-derived knowledge is given by the work on the role played by ash. Although the thesis only investigated the chemical characteristics of town refuse ash (7.1), the interviews with the farmers were enlightening in regards to all the functions of this material. In many cases, their statements could be matched to the outcomes of studies on the physical effects of wood ashes or coal-fly ashes (7.2).

4. Farmers' knowledge cannot identify or solve every agricultural problem. There are visible gaps in their expertise that need addressing, and this is where 'scientific' research is complementary to farmers' research. For example, although farmers have a strong understanding of the effects of ash, they do not perceive the dangers in switching from farm ash to town refuse ash (7.3). Heavy metal contamination is a real threat but it cannot be readily perceived.

9.1.1.5 Future trends

1. Manure is likely to continue being scarce in the near future. There already are problems of availability, and if DSIVP continues to expand, it will become increasingly scarce (5.4).

2. Town refuse ash, or compost, will probably become alternatives to manure, if the problem of petrol shortages in Jos is resolved (5.4).

3. If farmers cease using ash and other organic amendments, and rely exclusively on IF, there is a danger that soils will acidify and degrade (5.4).

9.1.2 The sustainability of the local agricultural system (aim 2)

The second aim of the thesis was to gain an insight into the sustainability (in terms of nutrient supply) of the local agricultural system. This was achieved, primarily, by carrying out case studies on the nutrient levels of four farms under different soil fertility management strategies. The results were then linked to data on socio-economic constraints pertaining to fertility maintenance. Although the findings cannot be extrapolated to the whole farming system, they still provide some important points for discussion, and a starting point for more extensive future work.

9.1.2.1 Methodological considerations

1. It is possible to distinguish long-term effects of cultivation (by comparing cultivated and control soils) (Model 1), however, with few exceptions it is not possible to detect short-term changes in nutrient variables over the course of the season (Model 2) (6.2.3).
2. Statistical analyses to distinguish between farms and IF recommendations based on average values are complementary approaches. For example, a statistically significant difference between two farms may not be important from an agricultural standpoint if the same IF recommendation is made for both farms. In other cases, two farms may receive widely different IF recommendations (based on mean values), but not be statistically different (6.1.2).
3. The soil analysis cannot be related to farmers' soil classification because it was not possible to obtain detailed information from the farmers, although they did have criteria to distinguish between soil types, in terms of texture, colour, frequency of irrigation and type of crops that could be grown (6.2.3.3).
4. The case study farm findings cannot be rigorously extrapolated to the whole farming system, but they were combined with general survey and interview data (Chapter 5) to provide an indication of what was happening more widely in the farming area.

9.1.2.2 Nutrient and heavy metal status of the case study farms (objective II)

1. The four case study farms Au, Ha, Sa and Sh were characterised by very low organic C, low or very low total N and slightly acidic pH. Their CEC was low, however, exchangeable bases, particularly Ca, dominated the cation exchange complex. With the exception of Ha, available P levels were sufficiently high so that P fertiliser was not necessary (Table 6-2). Ab and Mu were characterised by low organic C, very low total N, and slightly and moderately acidic (respectively) pH (Table 6-2).
2. Au, Ha, Sa, Sh and Ab were unlikely to have any problems of deficiency or toxicity of Fe, Mn, Ni, Zn, Cu (according to the soil tests). Neither Cd nor Pb exceeded the EEC maximum allowable levels for any of the farms, although Sh's farm's soil Pb was considerably higher than the rest and fell between the lower and upper EEC limits, which gives cause for some concern (6.1.2).

9.1.2.3 Long-term effects of cultivation practices (objective III)

1. Cultivation practices are affecting these farms in various ways (6.2.3). There are some common long-term trends. For example, all farms are experiencing a decline in organic C, total N, exchangeable K and Mg and available Mn (6.2.3.1).

2. Other findings are farm-specific. For example, there is evidence of Zn, Cu and Cd enrichment in Ab and Sh's cultivated soils compared to the uncultivated sites (6.2.3.1).

3. Texture is a controlling factor for the levels of CEC and exchangeable Mg and, to a lesser extent, exchangeable Ca. It may also play a role in controlling Ni and Cu, although in some locations (such as Ab's farm), Cu levels may be strongly affected by cultivation practices (such as the application of refuse ash) (6.2.3.2).

4. In terms of Fe, texture does not appear to be a controlling factor, even though farms are strongly differentiated and there is no effect of cultivation. Possible controlling factors of Fe availability include soil pH, organic matter and the amounts of other nutrients such as P, Cu, Zn and Mo (6.2.3.2).

9.1.2.4 Short-term (seasonal) effects of cultivation practices (objective IV)

1. There are few detectable seasonal changes in nutrient levels (6.2.3).

2. Organic C is the only variable that rises significantly at the end of the season in respect to the beginning, in all farms (6.2.3.1).

3. pH fluctuates quite dramatically over the course of the season, probably in response to a combination of factors: application of fertilisers, addition (through irrigation water), deposition (through Harmattan dust), removal (through crop uptake), and leaching of exchangeable bases. The fluctuations could not be related to any particular fertilisation episode. There is no clear-cut pattern that is common to all farms, although there is a tendency for the pH to drop during the course of the season, and then, rise to or above initial levels, by the end of the season (6.2.4.2).

9.1.2.5 Heavy metal accumulation in the soil and the food chain (objective V)

1. There is some evidence of heavy metal accumulation in the soil (point 2 in 9.1.2.3), although the absolute heavy metal levels in the cultivated soils did not suggest that there would be problems of toxicity (point 2 in 9.1.2.2).

2. All crops analysed had mean concentrations of Pb that are 20 to 40-fold higher than the FAO/WHO (2001) maximum recommended level for the consumption of vegetables (6.4.3).

3. There is evidence that carrots are hyper-accumulating Cd, as concentrations are ten times the limit proposed by FAO/WHO (2001) (6.4.3).

4. There is evidence of Pb accumulation in Ha and Ab's lettuce, which cannot be explained by the soil levels (6.4.3).

9.1.2.6 Linking soil nutrient levels in the case study farms to fertilisation practices

1. The decline in organic C in all four farms (6.2.3.1) is an indication of a reduction in organic matter (which typically occurs with cultivation). Associated to this is the decline in total N, exchangeable K and Mg and available Mn (although the decrease of these last three could also be attributable to crop uptake) (6.3.3).
2. Out of four case study farms, three farms were applying adequate amounts of P fertiliser to meet the crop's seasonal demands (6.4), and one of these farms presented evidence of soil P enrichment (6.1.2). One farmer did not apply sufficient IF for that season (6.4) and there was evidence of soil P depletion (6.1.2).
3. In terms of K, the farmers were applying sufficient amounts of fertiliser, to meet their crops' seasonal demands (6.4), yet K levels were declining in the cultivated soils in respect to the uncultivated sites (6.1.2).
4. In comparison to Alexander's (1996) analyses, soil P and K levels have increased (6.5).
5. Sh and Ab's cultivated soils are enriched with Zn, Cu and Cd in respect to the controls (6.2.3.1), and this is likely to be a consequence of the past and present use of town refuse ash (6.3.3).

9.1.2.7 Scaling up from case studies to the whole farming system

1. On average, farmers apply between 500 and 1000kg ha^{-1} of plant nutrients, which is close to consumption patterns in developed countries (5.2.4). Therefore, it is likely that most farms in the farming area follow the patterns of the case study farms, having reached high levels of P and K (6.5), although there may be instances of soil P mining (6.1.2).
2. The widespread decline in the use of organic inputs in Delimi (5.2.3) and the increasing reliance on IF (point 3 in 5.1.1), associated with the decline in organic C in all study farms (6.2.3.1), suggests that the majority of farms in the study area are likely to be experiencing the same trend of a decrease in organic matter (6.5).
3. The case study results cannot be extended to Rayfield, however, as this area still relies on large amounts of poultry manure and ash (5.2.3), it is probable that farms in this area would not have a problem of declining organic matter (or it would be much slower than Delimi), but could have a problem of heavy metal accumulation (6.5).

9.1.3 The role played by urban waste ash and the risks attached to its use (aim 3)

The third aim of the thesis was to contribute to the understanding of the role played by urban refuse ash and to highlight the risks attached to its use. This was accomplished by: analysing ash samples collected from the farms, and from around the town, to determine their potential nutrient and heavy metal contribution (objective VI); and interviewing farmers about the effects of ash (objective I).

9.1.3.1 Chemical characteristics of urban waste ash (objective VI)

1. Ash is not a homogeneous substance. It is extremely variable (Table 7-3). This means that the nutrient supply will vary considerably from batch to batch.
2. Typically, urban waste ash has a high pH and is rich in total Ca, K, Mg, Fe and Mn (7.1.1). This means that it can potentially raise the pH of acidic soils and can contribute essential nutrients that are not supplied through IF (7.1.2.5).
3. Present-day ash would not be considered contaminated, using EEC guidelines. However, although mean and median trace metal levels in the ash collected around Jos were not high, there is potential for very high peak levels for certain elements (such as Pb), so certain batches could create 'pockets' of contamination. Cadmium levels are below the EEC guidelines, nevertheless, they are sufficiently high to be of some concern (7.1.2.6).

9.1.3.2 Modes of action

1. Ash had multiple functions, as the interviews with the farmers revealed. It was beneficial to both soil and crops. Ash was applied, either at the preparation stage, before planting, when farmers wished to improve the soil's characteristics or, if the soil did not require improvement, the ash was applied once the crops had developed to a considerable size. In the latter case, most of the ash fell on the crops and relatively less fell on the soil. It is speculated that, in this case, the benefits of the ash are through foliar fertilisation (7.2.2).
2. The observations of the farmers on the effects of ash, in many cases, tie in with the findings of studies on the physical effects of wood or coal-fly ashes or, at any rate, some effects can find a 'scientific' explanation (7.2.1).
3. The points listed in 9.1.1.3 about general SFM practices are applicable to the use of ash.

9.1.3.3 Health hazards associated to the use of town refuse ash

1. Farmers are not aware of the health and environmental risks associated with the practice of using town refuse ash (7.3).
2. Farmers burn the waste, prior to sorting, because it is less arduous and more pleasant to handle in this form. This practice, though, can release heavy metals into the ash and cause environmental pollution (7.3).
3. The possibility that ash can work through foliar fertilisation (7.2) raises the concern that there may also be uptake of toxic trace metals, when ash is deposited on the surface of the crops (7.3).

9.1.4 Viewing soil fertility within the broader context of farming problems (aim 4)

The final aim of the thesis was to relate the major findings of SFM to the broader context of general farming problems (as perceived by the farmers and as perceived by the governmental extension service) (objective VII).

9.1.4.1 Methodological considerations

1. The survey and the in-depth interviews, which were used to investigate farming problems, did not always yield the same results. However, these two methods should be considered complementary (8.1.1).
2. Prioritisation of farming problems is heavily linked to farmers' individual circumstances and the urgency of the problem. A farmer was more likely to emphasise a problem that was afflicting him at that moment, even though all problems affect all farmers, at some stage or another. Environmental conditions could also determine the type of problems mentioned by farmers, especially minor ones (e.g. differences between Delimi and Rayfield). Additionally, timing of the survey and the interviews could have affected the type of answers given by the farmers (8.1.1).

9.1.4.2 Farming problems as perceived by farmers

1. The major problems in Delimi were finance, petrol, IF, pump engines, seeds and labour. In Rayfield they were finance, IF, petrol, pump engines, labour, and weeds (Table 8-1).
2. Finance was farmers' major constraint. Farmers thought that most other problems could be resolved with sufficient capital (8.1.1.1).
3. The problem of petrol acquisition was partly related to a problem of cost, but also to scarcity. The whole of Nigeria is having problems with petrol availability, so although small amounts are available at government–subsidised prices, farmers have difficulty accessing this, and frequently have to purchase petrol on the black market (8.1.1.1).
4. The problem of obtaining a pump engine was a highly controversial issue, because of a World Bank irrigation project, that is supposed to provide subsidised pump engines to promote dry season farming. Farmers felt that the project was not being administered properly by PADP (8.2.3.1), and this resulted in a degree of animosity against PADP.

9.1.4.3 Farming problems as perceived by PADP

1. PADP's issues were primarily concerned with: the over-application of agro-chemicals (that could lead to environmental pollution); importation of poor-quality farming inputs (agro-chemicals and seeds) through informal channels; pest damage; excessive irrigation; over-production of vegetables (that caused market prices to drop drastically); the decline in soil

fertility (which was prompting them to convince farmers to use organic inputs) (8.2.2 and 8.2.2.1).

2. There were areas of overlap between farmers' concerns and PADP's views, such as the issue of pest control (8.2.4.1).

3. However, there were also mismatches between PADP and farmers' views on farming problems. For example, PADP planned to encourage farmers to use organic inputs, but were not fully aware of the fact that farmers were already using organic inputs and, in fact, were complaining about high cost and scarcity. PADP were concerned with farmers using poor-quality inputs (expired seeds, adulterated pesticides, etc.). Farmers acknowledged that PADP's resources were of high quality, but PADP's headquarters were distant, they did not stock sufficient supplies, and they were expensive (8.2.4.2).

4. PADP viewed the World Bank sponsored irrigation project (the NFDF) positively (8.2.3.2). Yet, it is clear that there has been poor communication between the organisation and the farmers. They were not aware of the dissatisfaction amongst the farmers, caused by the limited distribution of the pump engines, and the excessively high down-payment requested for a pump engine (8.2.4.3).

9.1.4.4 Relating farmers' problems to the thesis' findings

1. Although soil degradation does not represent an immediate threat, there is a worrying trend of a decline in organic matter that is likely to continue, or even be accelerated, by reduced use of organic inputs. The increasing reliance on IF is worrying, particularly when it is considered that the use of ash is waning. Without the liming effects of ash, the soils may acidify and degrade under the continued use of IF (8.3.2).
2. Farmers, though, are faced with too many short-term concerns, to be able to consider soil fertility. These problems need to be resolved before any steps can be taken regarding SFM (8.3.2).
3. The provision of credit facilities could probably resolve many of the short-term concerns for farmers, particularly small-scale ones. Once these were resolved, farmers would be more receptive to the problem of SFM. However, not all the problems identified by the thesis could be solved through credit facilities for farmers. For example, the scarcity of organic amendments cannot be easily solved, as the solutions proposed would require a heavy investment on the part of the government (8.3.3).
4. An important step towards solving farming problems is to train extension agents in participatory methods. Even though PADP suffer from inadequate funding, increasing dialogue with the farmers on an equal basis would help resolve many issues, without the need for large amounts of resources.

9.2 FUTURE WORK

The thesis has identified areas that require either completely new, or follow-up research.

1. The problem of ever-increasing scarcity of organic amendments in the near future needs to be explored further. If farmers were to rely exclusively on IF, the stability of the system could be jeopardised. This research should be based on investigating whether all the sources of manure have been exhausted and, if not, what is constraining the farmers, and how these constraints can be removed. If this is the case, the viability of promoting livestock keeping on a large scale, or alternative management practices of urban waste, should be explored. Farmers were questioned about compost making and, although most were familiar with the technique, they claimed that it was excessively labour intensive. There is the need to determine whether a large-scale compost-making facility or incinerator plant could be successfully set up, and maintained.

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2. The content of Cd in carrots and Pb in lettuce from the study farms surpasses the maximum levels recommended by FAO/WHO (2001). For this reason, a more extensive follow-up study is necessary to determine if this is an actual problem and, if it is, the extent of it. The study should also look into consumption patterns of vegetables on the Jos Plateau, and, more widely in Nigeria, to determine the average dietary intake of trace metals.

3. DTPA-extractable levels of Pb and Cd in the soil and total concentrations of Pb and Cd in the crops from the field trials do not correlate well. Further research with alternative extracting agents is required.

4. The fertilising action of ash through foliar uptake needs to be investigated. The research carried out so far suggests that crops may take up nutrients from the ash deposited on the leaves. It is also possible that crops can take up toxic elements, such as Pb, Cd and Ni, in the same way, as well as other organic pollutants in the ash.

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5. Plant availability of nutrients in ash remains to be determined. The urban waste ash analysis in this thesis concentrated on the determination of total amounts of nutrients and heavy metals. Elements, though, can be present in different forms, so there is still need to evaluate what part of the total amount is immediately plant available.

6. Other risks of using town refuse ash need to be explored, such as pathogen and organic pollutant contamination of the material. Although farmers burn the waste, temperatures may not be sufficient to sterilise it. Burning may also cause environmental pollution.

7. The risks of using effluent water need to be assessed. This practice occurs in Anglo-Jos: farmers in this location use effluent water from the local industry for irrigation. This could result in contamination of soils and crops by chemical substances, pathogen contamination,

and health problems to the farmers, such as skin irritation/diseases, inhalation of toxic fumes, etc.

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8. A project to identify effective and environmentally–friendly pest treatments or, perhaps, a campaign to educate farmers on the correct and timely application of pesticides, is urgently required. Pest infestation appears to be a rising problem and yet, as reported by Porter *et al.* (2002), farmers only seem to have a basic knowledge about plant pests and diseases and are using chemical pesticides inappropriately and in excess. This has serious environmental implications.
9. Ways of re-connecting the farmers to PADP and other farming-related bodies need to be explored. After providing the extension agents with training in participatory techniques, it is vital to explore how extension agents can engage in fruitful dialogue with as many farmers as possible. With the little funding available to PADP, one possibility is to use the FUAs to call regular meetings that would act as forums of discussion, and possibly, teaching classes for basic farming-related issues.

9.3 CONCLUDING REMARKS

In summary, the thesis has shown that, on the whole, farmers are knowledgeable in the maintenance of soil fertility and generally very skilled in their activity. There is a need for governmental (and, indeed, any non-governmental or external) agencies to recognise this. They should be more sensitive to farmers' needs and requests and, as Reij and Waters-Bayer (2001a) have already observed, it is critical that any agricultural development project should incorporate farmers' input at the *planning* stage (a situation apparently not recognised by either PADP or the World Bank).

Scientific research has a lot to offer farmers, particularly in the early identification of environmental problems caused by farming activities, but it needs to understand farmers' concerns and priorities first. Tacit (or informal) knowledge and 'scientific' expertise are complementary and can be brought together, but a middle way must be found between always addressing farmers' short-term concerns (disregarding long-term environmental problems), and running a project on what the scientists think the farmers need. The Nigerian Government needs to embrace this idea in its extension services. PADP have identified valid farming problems, but equally they do not understand the existing expertise of the farmers. There is a need to move away from ToT approaches, to solve these problems. If farmers do not recognise a problem, they will not apply the solution proposed by the extension service.

One strong reason why there is need for two-way discussions is that, frequently, ToT solutions are too rigid for the farming environment. The thesis emphasised at various stages that, although farmers had certain work plans, they frequently did not adhere to them. This is because the farmers' environment is dynamic and they need to respond swiftly to fluctuating market forces, availability of inputs, unexpected circumstances, etc. This means that if an extension agent's proposal is adopted, it is adapted and modified to suit the environment (Rhoades, 1989). This is what happened when farmers incorporated IF into their traditional SFM strategy.

Therefore, PADP need to interact with the farmers, and work with them to find low-input, dynamic solutions, that can be modified to suit differing circumstances. The NFDF World Bank sponsored project is an example of a project that, in the farmers' eyes, has been a failure. The project was designed for the drier States of the North, and consisted of a subsidised package of a tubewall installed by washboring, and a pump engine. It could only be installed as a package (at least in the 1995-1998 phase of the project) and, as such, it was unsuited to the conditions on the Plateau, because of the abundant surface water available. The farmers wanted access to the pump engines (which PADP successfully procured and placed in store), but PADP could not distribute them without a washbore. Despite the fact that the World Bank has insisted on farmer involvement and this has successfully led to the formation of farmer associations (i.e. the FUAs), there is no feedback mechanism in place, so that neither PADP, nor the farmers are able to change the conditions of the project. Schalatek and Unmüssig (2002) have indicated that this is typical of World Bank development projects.

As well as better communication between farmers and extension services, it is recommended that PADP should facilitate access to credit facilities. Given that PADP is severely under-funded, there is little that the organisation can do for farmers at the present time. Negotiating credit facilities would allow farmers to solve many of their own problems independently, although it would not be a panacea. There is still need for collaboration between farmers and scientists, as there are problems that the scientists can identify that farmers may not be aware of.

For example, credit facilities are not sufficient to address the problem of organic amendments. The thesis has demonstrated that, although the farmers claim to use the same SFM strategy as reported in the 1990s (Phillips-Howard and Kidd, 1991), in practice it has changed significantly, as farmers have reduced the amounts of organic inputs quite drastically. This can be explained by a variety of factors, such as the high cost of transport (which reduces the distance a farmer is willing to travel to, to obtain manure or ash), and the expansion of DSIVP in the last decade (Porter *et al.*, 2002), which leads to pressure on scarce supplies of organic manure.

The future of the system is uncertain. Although the case studies suggest that the system is not immediately threatened, the reliance on IF could lead to soil acidification (especially with the disappearance of CAN, which is the only non-acidifying IF), which will reduce the availability of nutrients and the stability of soil structure. This is likely to occur sooner in an area like Delimi where, for various reasons, the use of manure and town refuse ash has declined considerably compared to Rayfield. Unfortunately, it seems that the success and expansion of DSIVP in the last decade could actually promote its collapse: as DSIVP continues to expand, farmers are faced with problems of water shortages, increasing pest infestation (Porter *et al.*, 2002), IF and manure scarcity, which will worsen, as more and more pressure is put on the environment. Although farmers are aware of some of the implications of using IF in the long-term, the short-term pressures are such that they may be forced, nevertheless, to rely on IF, to the detriment of their environment.

Another area that requires collaboration between farmers and scientists is that of the use of urban waste ash as a fertiliser. The chemical analyses carried out for this thesis have contributed to filling the gap in the literature on the range of nutrient and trace metal levels in town refuse ash, produced by burning *in situ*. They have shown that, although on the whole, town refuse ash is not heavily contaminated with trace metals, Cd levels are quite high, and there can be high peak Pb levels. This implies that there is potential for heavy metal accumulation in the soil (albeit slowly), or directly, through foliar uptake. However, farmers do not seem to be aware of the health implications of using waste materials in farming, as testified by the uncontrolled burning of refuse (which can result in unpleasant and polluting fumes being emitted into the atmosphere), the lack of sorting prior to burning (which may be more hygienic for the farmers but may lead to the release of heavy metals), and the application of ash directly *on* the crops (potentially causing foliar uptake of trace metals). There is an urgent need to raise farmers' awareness of these issues, but there is the risk that they are not going to be receptive unless viable alternatives to these practices are offered to them. Scientists can identify and carry out research on alternatives, but it is the task of the Federal Government of Nigeria to release sufficient funding, first to educate farmers on these health hazards, and second to facilitate alternative waste management practices, such as a composting or incineration plant.

As a final point, it is important to address the issue of dissemination. Although farmers did not actively participate in the field trials, there was a strong feeling that they should obtain feedback from the thesis, in exchange for their co-operation. For many, the condition of granting an interview was that they should have the results in return. It did not concern them that it would require some time, or that the results would be of little immediate use to them. To them, it was the act of returning the results that counted, rather than the actual outcome of the research. This was probably the consequence of having been previously interviewed by several researchers, who had either never returned to the site, or who had, but had not provided farmers with feedback. This has caused a feeling of disappointment and despondency, as they felt that they had taken time to be co-operative, and yet nothing had changed in their lives.

However, the process of giving farmers feedback is subject to some ethical considerations. One source of conflict in participatory development is about whose concerns should be addressed first. Should farmers' priorities be given precedence? What happens when the development organisation, which is working with the farmers, feels that, by adopting a particular solution (advanced by the farmers), a long-term issue is ignored, generated or aggravated? The development organisation can wield a lot of power, through its resources and its contacts, so it can ultimately decide whether to work on the farmers' choice of problems or its own agenda. The problem is that, in some circumstances, the farmers may be right and the development agency wrong, and in other cases, the development agency may actually have a longer-term perspective, and can foresee outcomes that the farmers cannot. The development agency has a big responsibility if the project fails. If it prioritises farmers' problems, even when it feels that this is wrong, and the long-term outcome *does go* wrong, then it is responsible for not having used its knowledge and resources to avert the problem. If, on the other hand, it overrides the farmers' concerns, it has a double responsibility: farmers may not adopt the solution proposed and, hence, the organisation has wasted time and resources, or, farmers may adopt the solution and, if this results in a negative outcome, the organisation precipitated this.

Although this thesis is not a development project, it is afflicted by the same dilemmas. It needs to make recommendations, but these recommendations could potentially be *wrong*.

I am faced with an ethical problem: if I make my recommendations, and the Nigerian government chooses to act upon them, and this worsens the farmers' conditions because I was mistaken in my judgement, I will feel responsible, but I will not suffer any material consequences. If I choose not to make any recommendations I will be absolved from potentially making a mistake, but I will be guilty of having 'used' the farmers for my own purposes. I could choose to disregard my promise of returning results to them, but this will jeopardise future research in the area, and it will invalidate my belief that a research student has obligations towards the people s(he) is working with.

I have chosen the path of returning my results to the farmers, to PADP, JMDB and FUA. Although I may make a mistake, I feel that it would be a bigger mistake not to make any recommendations. Ultimately, I have no decisional power, I can only suggest and advise, and it is the decision of the people receiving my feedback to consider my advice or discard it.

Returning results to the farmers will be a demanding task because the 'scientific' results need to be digested into an easily communicable and understandable format, for farmers who, for the most part, do not read or write English, or even Hausa. This could be achieved with simple cartoon leaflets or, perhaps, radio dissemination. The use of governmental extension services may be an option for the future but, at present, the meeting with PADP revealed that efficient extension structures are not in place, so this means of communication is severely limited. An alternative way would be to use FUA, but as Nigerian society is strongly based on hierarchical structures, the information may not filter down rapidly to the lower ranks of the farmers. Ultimately, personal contact is probably the best way of engaging with the farmers. It might attain less but it should be more meaningful because farmers would feel that someone has committed to them. Hopefully, it will establish a climate of trust that will be conducive to properly participatory, research projects in the future.

Overall, the experience of conducting inter-disciplinary research has been challenging and rewarding, and has provided a wider understanding of issues surrounding the characteristics of the current soil fertility management practices, the sustainability of the farming system, and the role played by urban waste ash.

However, the assessment of how important soil fertility is in relation to wider farming problems has shown that farmers will not be in a position to use the results in the immediate future, because of the short-term constraints they face.

It is, therefore, the role of the Nigerian government to take up the challenge of removing short-term constraints to farming, and address longer-term issues, in a participatory framework. If the system is to be stable, it is imperative that action is taken now.

APPENDIX A: Questionnaire survey and interview questions

A1. Questionnaire administered during the dry-season irrigated farming survey (4.7.1):

1. Location.
2. Name of plot farmer.
3. Sex of plot farmer.
4. Age.
5. Ethnic group.
6. Religion.
7. Level of education.
8. Place of birth.
9. Resident.
10. Marital status.
11. Number of wives (only if respondent is male, otherwise consider as number of co-wives).
12. Number of children.
13. Occupation: (i)Principal; (ii)Others.
14. For how many years have you been a market gardener?
15. Size of garden (total number of subplots).
16. Site location of garden: □Fadama (i.e. River floodplain), □Mine paddock, □Slope, □Upland plain.
17. Initial improvements made on gardening land: □Levelling, □Terracing, □Stone breaking.
18. Form of Land Tenure: □Inheritance, □Purchase, □Hired, □User right, □Share cropping, □Pledged, □Allocation.
19. Vegetables grown (make a list in order of importance for the respondent).
20. What type of soil improvement do you use? Type of inorganic fertiliser, manure or urban waste ash, amount bought, cost, amount applied/local land unit.
21. Which fertiliser(s) do you prefer? Why?
22. Do you use pesticides? Type of pesticide, amount bought, cost, amount applied/local land unit.
23. Types of crop disease.
24. Labour inputs.

Source	From where?	Number	Operations performed	Payment (rate and mode)
Family	N.A.			
Hired				
Co-operative				

25. Source(s) of irrigation water.

26. Improvements made to the source of water: □Sink shallow wells (especially on river basin floor), □Damming of streams/mines, □Deepening and enlarging mine ponds, □Others (specify).
26. Method(s) of irrigation.
27. Frequency of watering per week.
28. Time spent on watering (one session only).
29. Marketing of produce: Crop type, place of sale, mode of sale, by whom, how transported to place of sale.
30. Length of the market gardening seasons (i) Start of market gardening (1999/2000), (ii) End of market gardening (1999/2000).
31. What factors do you think affect your crop yields?
32. What are your major problems? (make a list).
33. Occupation(s) during off-dry season market gardening.
34. If farming, where?
35. Size of farm.
36. Crops grown.
37. Who owns the land?

A2. Questions asked during the semi-structured interviews on fertiliser strategies (4.7.3.1):

1. What type of fertiliser are you going to apply this year?
2. How do you apply it, how many times, how much.
3. Do you use any other types of fertiliser?
4. Why do you use ash? *Or*: What effects does ash have?
5. How do you get your ash?
6. Do you have any preference concerning fertilisers?
7. *Other questions depending on how interview proceeds.*

A3. Questions asked during the un-structured interviews on farming problems (4.7.3.2):

1. What type of problems do you face in your business?
2. *Questions for further clarification.*
3. *Open-ended questions if farmer was not forthcoming during the interview.*

A4. Questions asked during the un-structure interviews on cropping patterns (4.7.3.3.):

1. What are your motivations for mixing certain crops together? For example, over there you only have lettuce but here you have spinach, lettuce and cabbage…
2. *If necessary*: can you explain more? Any other reasons?

A5. Questions asked during structured interviews in Rayfield on the use of urban waste ash (4.7.4):

1. Do you use ash?
2. Where do you get it from?
3. How do you transport it?
4. How much do you get? How many trips?
5. Is there any difficulty in obtaining the ash?
6. Do you make arrangements with JMDB and if so, how much do they charge you?
7. Why do you use ash?
8. Do you prefer modern (inorganic) or traditional (organic) fertiliser?

APPENDIX B: Analytical techniques

B1 Methods for soil samples

B1.1 Method to check for analytical consistency

1. Repeat runs were carried out on a limited number of samples to crosscheck that the analytical method was yielding consistent results. Overall, about 1 in 10 samples were duplicated.
2. A second method of checking was based on internal consistency. Some degree of variation between subplots on the same farm (spatial variation) and within the same subplot over time (temporal variation) would be expected but if any samples appeared to be unusually high or low (in respect to the other samples) for any one variable, they were repeated.

B1.2 Wavelengths and standard solutions used to determined exchangeable bases on the AAS (4.4.2.9)

1. Wavelengths and standards used to determine each element were the following:

1. Sodium	wavelength:	589.6µm;	Standards:	0.2, 1, 2ppm
2. Potassium	wavelength:	766.5µm;	Standards:	0.1, 1, 2ppm
				0.5, 1, 5ppm
3. Calcium	wavelength:	422.7µm;	Standards:	0.3, 1, 3ppm
4. Magnesium	wavelength:	285.2µm;	Standards:	0.1, 0.5, 1ppm

If the leachate displayed absorbance readings that were out of range of the calibration curve, it was diluted appropriately, and then the concentration reading multiplied by the dilution factor to obtain the correct concentration reading.

B1.3 Anomalies in the sodium results

All sodium results must be interpreted with caution as the laboratory analyses revealed some anomalies. Various logistical reasons (mainly a breakdown of the Atomic Absorption Spectrophotometer–AAS) meant that the samples had to remain in storage in the fridge for a long time. Analysis of the first batch had been started and interrupted following technical problems with the AAS. When the problem was finally resolved, the samples that had already been run through were run again for homogeneity in testing conditions. The old results and the new results were compared and whereas calcium, magnesium and potassium showed close agreement, the sodium showed high discrepancies. The new results appeared a lot lower than the original run. A series of tests (where a diluted sample was run one day and kept overnight and run again the following day) showed that sodium results varied quite significantly from day to day. No explanation could be found, and none of the standard textbooks consulted seemed to mention the problem, even though the technical staff had noticed similar problems before and suggested that the sodium reacts in some way with ammonium acetate (Davis, Pers. Comm.). Ideally, the samples should be run through the AAS as soon as they are ready, but in normal laboratory conditions this is not always feasible. When the problem was discovered, the remedy was to subsequently freeze the remaining batches until they could be analysed on the AAS.

B1.4 Analytical method for available iron, manganese, zinc, copper, nickel, cadmium and lead (4.4.2.11)

Available metals were extracted from the soil with diethylene-triamine-pentaacetic acid (DTPA) extracting solution. The solution is a mixture of 0.005M DTPA, 0.1M triethanolamine (TEA) and 0.01M $CaCl_2$, adjusted to pH 7.3.

The method consisted of the following steps:

1) Polythene bottles for the test were cleaned up for any possible contaminants with a dilute HCl solution. After the acid wash, they were rinsed several times with de-ionised water and air-dried.
2) 10g of oven-dry soil was weighed into a clean polythene bottle and 20ml of DTPA extracting solution was added and placed into a horizontal shaker for 2 hours.
3) After 2 hours the solution was centrifuged at 2000 revolutions per minute for 10 minutes and then filtered through Whatman N° 542 filter paper.
4) The filtrate was analysed on an Atomic Absorption Spectrophotometer (Model: Varian Spectra AA 220FS) for the elements Fe, Mn, Zn, Cu, Ni, Cd, and Pb.
5) As the elements were numerous it would not have been viable to dilute samples to different degrees to always use the more sensitive wavelength for each element, also because there was not much sample available. If the majority of samples could be analysed on the most sensitive wavelength without dilution, this was done, otherwise a less sensitive but wider range wavelength was chosen. Generally the wavelengths and standards for each element were the following:

1. Iron	wavelength:	372.0μm;	Standards:	5, 15, 50ppm
				15, 50, 100ppm
2. Manganese	wavelength:	403.1μm;	Standards:	5, 20, 60ppm
3. Zinc	wavelength:	213.9μm;	Standards:	0.1, 1, 2ppm
4.Copper	wavelength:	324.8μm;	Standards:	0.1, 5, 10ppm
5. Nichel	wavelength:	232.0μm;	Standards:	0.1, 0.5, 1ppm
				0.5, 1, 5ppm
6. Cadmium	wavelength:	228.8μm;	Standards:	0.1,1,3ppm
7. Lead	wavelength:	217.0μm;	Standards:	0.5, 1, 5ppm

B2 Analytical method for the determination of total (acid extractable) heavy metals and base cations in ash samples(4.4.3.3)

The determination of total (acid extractable) Na, K, Ca, Mg, Fe, Mn, Zn, Cu, Ni, Cd and Pb on ash samples was carried out with microwave-assisted digestion. The procedure is as follows:

1) The samples were oven-dried for accurate and precise determination of the sample weight.
2) 1/2g of sample was weighed accurately to four digits into the microwave vessels.
3) 4ml of hydrogen peroxide was gradually added to the vessels and these were left overnight for all the organic matter to be destroyed.
4) 10ml of concentrated nitric acid was added to each vessel, left to stand for 10 minutes and then the vessels were placed in a CEM MARSX Microwave system on EPA's method 3051 cycle.
5) After cooling, the vessel contents were washed into 100ml flasks with de-ionised water and tested on the Atomic Absorption Spectrophotometer (Model: Varian Spectra AA 220FS) for all the required elements.
6) The elements were always measured on the most effective wavelength, but for speed and simplicity, if the samples were greatly out of range, a less precise wavelength with a wider range was used. The following wavelengths and standards were used, (where necessary samples were diluted):

1. Sodium	wavelength:	330.2μm	Standards:	5, 20, 100ppm
2. Potassium	wavelength:	404.4μm	Standards:	30, 100, 500ppm
3. Calcium	wavelength:	239.9μm	Standards:	50, 100, 750ppm
4. Magnesium	wavelength:	202.6μm	Standards:	0.5, 5, 20ppm
5. Iron	wavelength:	372.0μm	Standards:	5, 15, 50ppm
				15, 50, 100ppm
6. Manganese	wavelength:	279.5μm	Standards:	0.5, 2, 5ppm
7. Zinc	wavelength:	213.9μm	Standards:	0.1, 1, 2ppm
8. Copper	wavelength:	324.8μm	Standards:	0.1, 5, 10ppm
9. Nichel	wavelength:	232.0μm	Standards:	0.1, 0.5, 5ppm
				0.5, 5, 10ppm
10. Cadmium	wavelength:	228.8μm	Standards:	0.1, 1, 3ppm
11. Lead	wavelength:	217.0μm	Standards:	0.1, 0.5, 1ppm

B3 Analytical method for the determination of trace metals in crop samples (4.4.4):

The determination of total (acid extractable) Fe, Mn, Zn, Cu, Ni, Cd and Pb on crop samples was carried out with microwave-assisted digestion. The procedure is as follows:

1) The samples were oven-dried for accurate and precise determination of the sample weight.
2) 2g (for lettuce or cabbage) or 1.45g (for carrot) of sample were weighed accurately to four digits into clean tall-form beakers.
3) Beakers were placed on a hot-plate and samples were digested by gradual addition of a total 56ml hydrogen peroxide and 295ml de-ionised water.
4) After digestion samples were washed into microwave vessels with 30ml de-ionised water and 10ml concentrated nitric acid. Samples were left to stand for 10 minutes and then the vessels were placed in a CEM MARSX Microwave system on EPA's method 3051 cycle.
5) After cooling, the vessel contents were washed into 50ml flasks with de-ionised water.
6) Total Fe, Mn, Zn, Cu, Ni, Cd and Pb were determined for each sample on a PerkinElmer Elan 6100 DRC Plus ICP-Mass Spectrometer.

B4 Analytical method for the determination of trace metals in river water samples (4.4.5):

Water samples did not require any preparation apart from spiking with nitric acid . They were simply filtered with N° 542 Whatman filter paper and dissolved Na, K, Ca, Mg, Fe, Mn, Zn, Cu, Ni, Cd and Pb were determined on a PerkinElmer Elan 6100 DRC Plus ICP-Mass Spectrometer. The analysis was semi-quantitative, as the instrument was calibrated using a single solution.

APPENDIX C: Interviews at JMDB and PADP

C1. Interview at the Jos Municipal Development Board

JMDB was visited on one occasion so that an official representative could be interviewed on disposal practices of Jos' waste. JMDB services the localities of Jos North and Jos South. It has a collection schedule but as it is reduced to four operative tipper trucks (from 23) it is forced to collect from major areas only. The tipper trucks have a capacity of five and seven tonnes. The major industrial companies, such as NASCO and Jos International Breweries (JIB), have their own tipper trucks which helps reduce the pressure on JMDB but the problem is that these companies often dump indiscriminately. Other smaller industrial complexes are educated on how to store waste in a sanitary way while they await collection.

In contrast to the typical ways of disposing of waste (trenching, indiscriminate dumping, composting, incineration, stream dumping and control tipping), an alternative way of reducing the volume of waste is to give it to local farmers.

JMDB transports waste to the farms of those who request it, for no fee except petrol costs. The highest number of requests come from the farming areas in Zaria Road, Gangari and Delimi Langalanga, and it is predominantly dry-season farmers who require it. The farmers usually request dry waste but in some cases they may collect sun-dried sewage sludge. JMDB are aware of the health risks attached to the utilisation of urban refuse (because of the presence of sharp materials or hospital waste), particularly because burning it to ash does not sanitise it sufficiently, but affirm that the farmers persist in not using protective clothing (masks, rubber gloves, coveralls).

C.2 Launching of the FUA market

On 5 May 2001 the Fadama Users' Association officially commissioned its new market, based on Bukuru Road, not far from the Building Materials Market. The purpose of the market was to cut out the middlemen and allow farmers to sell their produce directly. Each group of farmers was allocated a portion of land on which to build a stall, so that no one stall would belong to an individual farmer. Each stall was supposed to function as a 'showroom', where farmers could display samples of their produce and make arrangements so that customers would come directly to the farm for their purchases. The FUA market was built for the purpose of allowing farmers to carry out their transactions without the intervention of the middlemen, but this did not mean that farmers were not free to continue using middlemen if they wished.

The express purpose for establishing the market was stated as: "In an effort to address the marketing problems of Fadama products, the Fadama Users' Association embracing all levels, established its own market. This market being commissioned is fully owned and managed by the FUA Apex body on behalf of all FUAs in the State" (FUA, 2001).

APPENDIX D: Inorganic fertiliser analysis

Table D1: NPK contents of various IF brands

FERTILISER TYPE	% N (TOT)[1]	%N (total)[2]	% N (soluble)[3]	% P_2O_5 (total)[2]	%P_2O_5 (souble)[3]	% K_2O (soluble)[3]
15:15:15 Plateau State	16.41	6.63	6.36	25.15	27.48	11.00
15:15:15 Golden	15.41	5.02	3.08	32.18	30.82	15.37
15:15:15 Kampa	16.73	8.36	6.85	33.74	31.23	16.01
20:10:10 Plateau State	22.46	10.99	8.86	21.74	21.87	9.84
17:5:5:17 Kaduna	33.99	0.43	0.01	3.75	2.34	2.83
27:13:13 Golden	30.63	0.81	0.10	20.38	17.05	9.14
Super-P	-	1.58	0.01	40.73	32.99	0.03
Urea	*46.91	0.08	0.01	-	-	0.00

[1]. Analysis carried out in triplicate, by high temperature combustion on an Exeter Analytical, Inc., CHN CE 440 Elemental analyzer. *Analysis carried out on a single sample.

[2]. Analysis carried out in triplicate, using a modified microwave digestion method for total N and P (on a CEM MARSX microwave system), recommended by CEM microwave systems, based on the potassium persulphate digestion method used by Johnes and Heathwaite (1992). NO_3^- and PO_4^{3-} were detected on a Dionex Ion Chromatography system, the DX500 system, using an AS15 5μm guard column and analytical column, using suppressed conductivity. Results were then converted to N and P_2O_5, respectively.

[3]. Analysis carried out in triplicate. Samples were dissolved in a known quantity of dionised water and tested for NO_3^- and PO_4^{3-} (which were then converted to elemental N and P_2O_5), using a Dionex Ion Chromatography system, the DX500 system, using an AS15 5μm guard column and analytical column, using suppressed conductivity. Elemental K was detected on an Atomic Absorption Spectrophotometer (Model: Varian Spectra AA 220FS) and then converted to K_2O.

APPENDIX E: Mean values for different variables for each of the farms' cultivated and control soils

Table E1: Untransformed means

Variable		*Au*	*Ha*	*Sa*	*Sh*	*Ab*	*Mu*
Org. C g $100g^{-1}$ or %	Cult.	1.18 (0.3)	1.09 (0.16)	1.01 (0.36)	0.77 (0.27)	0.65 (0.19)	0.52 (0.14)
	T2	1.22 (0.4)	1.06 (0.17)	0.94 (0.32)	0.67 (0.18)	0.71 (0.21)	0.51 (0.15)
	Cont.	1.69 (0.35)	1.57 (0.50)	1.46 (0.53)	1.52 (0.65)	0.79 (0.29)	0.53 (0.16)
Tot. N Log10(100*g $100g^{-1}$)	Cult.	1.07 (0.11)	1.02 (0.07)	0.96 (0.15)	0.94 (0.10)	0.76 (0.13)	0.74 (0.11)
	T2	1.11 (0.19)	1.01 (0.05)	0.91 (0.17)	0.92 (0.08)	0.83 (0.12)	0.77 (0.14)
	Cont.	1.19 (0.08)	1.09 (0.17)	1.05 (0.17)	1.06 (0.19)	0.84 (0.21)	0.72 (0.11)
pH	Cult.	6.5 (0.2)	6.8 (0.2)	6.2 (0.4)	6.5 (0.3)	6.6 (0.2)	6.0 (0.4)
	T2	6.6 (0.3)	6.6 (0.1)	6.0 (0.2)	6.4 (0.3)	6.4 (0.2)	5.9 (0.5)
	Cont.	6.0 (0.5)	6.5 (0.1)	6.4 (0.2)	6.4 (0.5)	6.3 (0.6)	5.6 (0.5)
Ex. K Log10(100*$cmol_{(c)}$ kg^{-1})	Cult.	1.79 (0.09)	1.78 (0.17)	1.76 (0.14)	1.68 (0.13)	-	-
	T3	1.82 (0.04)	1.79 (0.23)	1.79 (0.16)	1.66 (0.10)	-	-
	Cont.	1.8 (0.15)	1.97(0.25)	1.93 (0.23)	1.80 (0.23)	-	-
Ex. Na Log10(100*$cmol_{(c)}$ kg^{-1})	Cult.	1.90 (0.13)	2.14 (0.29)	2.15 (0.38)	2.07 (0.19)	-	-
	T3	1.92 (0.09)	2.35 (0.30)	2.30 (0.40)	2.07 (0.15)	-	-
	Cont.	1.96 (0.16)	2.04 (0.31)	2.08 (0.38)	1.70 (0.14)	-	-
Ex. Ca Sqrt(100*$cmol_{(c)}$ kg^{-1})	Cult.	37.40 (6.61)	35.14 (3.76)	30.43(6.68)	23.50(3.95)	-	-
	T3	36.67 (2.29)	33.78 (2.27)	34.21(3.90)	23.66(4.40)	-	-
	Cont.	37.32 (4.1)	32.14 (8.1)	32.63 (5.4)	26.79 (6.1)	-	-
Ex. Mg Log10(100*$cmol_{(c)}$ kg^{-1})	Cult.	2.24 (0.07)	2.33 (0.24)	2.08 (0.11)	2.07 (0.1)	-	-
	T3	2.22 (0.04)	2.34 (0.12)	2.11 (0.12)	2.09 (0.07)	-	-
	Cont.	2.39 (0.14)	2.33 (0.24)	2.17 (0.08)	2.19 (0.19)	-	-

Variable		*Au*	*Ha*	*Sa*	*Sh*	*Ab*	*Mu*
CEC $cmol_{(c)}\ kg^{-1}$	Cult.	13.75 (1.53)	13.3 (1.37)	8.59 (2.54)	7.90 (2.32)	-	-
	T3	14.05 (1.22)	13.00 (1.41)	8.81 (2.18)	8.67 (2.93)	-	-
	Cont.	14.76 (1.3)	12.63 (4.1)	10.17 (3.1)	10.37 (2.8)	-	-
Avail. P Sqrt(mg $100g^{-1}$)	Cult.	2.52 (1.01)	1.30 (0.44)	3.74 (0.82)	2.53 (0.56)	-	-
	T2	2.44 (1.23)	1.24 (0.46)	3.81 (0.95)	2.35 (0.58)	-	-
	Cont.	2.44 (1.65)	1.66 (0.68)	2.73 (0.74)	2.39 (0.94)	-	-
Avail. Fe Log10(mg kg^{-1})	Cult.	1.77 (0.06)	1.45 (0.07)	1.33 (0.08)	1.43 (0.15)	1.56 (0.06)	-
	Cont.	1.83 (0.15)	1.43 (0.16)	1.31 (0.17)	1.46 (0.12)	1.57 (0.07)	-
Avail. Mn mg kg^{-1}	Cult.	43.52(10.31)	40.04(5.09)	23.00(6.94)	36.44 (7.26)	48.04(20.37	-
	Cont.	45.10(21.78	61.50(17.11)	34.41(10.23)	46.50(14.87)	53.34(21.66)	-
Avail. Zn Sqrt(mg kg^{-1})	Cult.	3.40 (0.76)	2.79 (0.36)	3.40 (0.40)	3.32 (0.62)	3.56 (0.83)	-
	Cont.	3.67 (0.86)	4.02 (0.86)	3.79 (1.00)	2.18 (0.71)	3.05 (0.83)	-
Avail. Cu Log10(100*mg kg^{-1})	Cult.	2.55(0.13)	2.55(0.18)	2.14 (0.14)	2.43 (0.12)	2.58 (0.10)	-
	Cont.	2.56 (0.08)	2.52 (0.25)	2.08 (0.03)	2.04 (0.19)	2.42 (0.13)	-
Avail. Ni Log10(100*mg kg^{-1})	Cult.	1.87 (0.07)	1.59 (0.09)	1.28 (0.26)	1.47 (0.22)	1.53 (0.17)	-
	Cont.	1.96 (0.05)	1.67 (0.2)	1.25 (0.51)	1.41 (0.18)	1.44 (0.31)	-
Avail. Cd Log10(100*mg kg^{-1})	Cult.	1.05 (0.25)	0.86 (0.11)	0.92 (0.09)	0.99 (0.24)	1.27 (0.09)	-
	Cont.	1.47 (0.10)	1.01 (0.15)	0.93 (0.26)	0.71 (0.35)	0.78 (0.32)	-
Avail. Pb Log10(100*mg kg^{-1})	Cult.	2.43 (0.31)	2.70 (0.09)	2.72 (0.23)	3.41 (0.26)	2.70 (0.14)	-
	Cont.	2.16 (0.48)	2.93 (0.48)	2.82 (0.18)	3.26 (0.24)	2.66 (0.22)	-

The table contains mean values and standard deviations (in brackets). 'Mean cult.' = mean for cultivated based on all available pooled replicates (10, 20 or 30). 'Mean T2' or 'T3'= mean for one single time point (ten replicates). 'Mean cont.' = mean for the control (ten replicates).

Table E2: Mean values in original units

Variable Tested		*Au*	*Ha*	*Sa*	*Sh*	*Ab*	*Mu*
Organic C g $100g^{-1}$ or %	Mean cult.	1.18	1.09	1.01	0.77	0.65	0.52
	Mean T2	1.22	1.06	0.94	0.67	0.71	0.51
	Mean cont.	1.69	1.57	1.46	1.52	0.79	0.53
Total N g $100g^{-1}$ or %	Mean cult.	0.12	0.11	0.09	0.08	0.06	0.06
	Mean T2	0.13	0.10	0.08	0.08	0.07	0.06
	Mean cont.	0.15	0.12	0.11	0.12	0.07	0.05
pH	Mean cult.	6.5	6.8	6.2	6.5	6.6	6.0
	Mean T2	6.6	6.6	6.0	6.4	6.4	5.9
	Mean cont.	6.0	6.5	6.4	6.4	6.3	5.6
Exchangeable Na $cmol_{(c)}\ kg^{-1}$	Mean cult.	0.79	1.35	1.41	1.15	-	-
	Mean T3	0.83	2.24	2.00	1.17	-	-
	Mean cont.	0.91	1.10	1.20	0.50	-	-
Exchangeable K $cmol_{(c)}\ kg^{-1}$	Mean cult.	0.62	0.60	0.58	0.47	-	-
	Mean T3	0.66	0.62	0.62	0.46	-	-
	Mean cont.	0.74	0.93	0.85	0.63	-	-
Exchangeable Ca $cmol_{(c)}\ kg^{-1}$	Mean cult.	13.99	12.35	9.26	5.52	-	-
	Mean T3	13.45	11.41	11.70	7.18	-	-
	Mean cont.	13.93	10.33	10.65	7.18	-	-
Exchangeable Mg $cmol_{(c)}\ kg^{-1}$	Mean cult.	1.74	2.14	1.20	1.17	-	-
	Mean T3	1.66	2.19	1.29	1.23	-	-
	Mean cont.	2.45	2.14	1.48	1.55	-	-
CEC $cmol_{(c)}\ kg^{-1}$	Mean cult.	13.75	13.30	8.59	7.90	-	-
	Mean T3	14.05	13.00	8.81	8.67	-	-
	Mean cont.	14.76	12.63	10.17	10.37	-	-
Available P mg $100g^{-1}$	Mean cult.	6.35	1.69	13.99	6.40	-	-
	Mean T2	5.95	1.54	14.52	5.52	-	-
	Mean cont.	5.95	2.76	7.45	5.71	-	-
Available Fe mg kg^{-1}	Mean cult.	58.88	28.18	21.38	26.92	36.31	-
	Mean cont.	67.61	26.92	20.42	28.84	37.15	-
Available Mn mg kg^{-1}	Mean cult.	43.52	40.04	23.00	36.44	48.04	-
	Mean cont.	45.10	61.50	34.41	46.50	53.34	-
Available Zn mg kg^{-1}	Mean cult.	11.75	7.78	11.56	11.02	12.67	-
	Mean cont.	13.47	16.16	14.36	4.75	9.30	-
Available Cu mg kg^{-1}	Mean cult.	3.63	3.63	1.38	2.69	3.80	-
	Mean cont.	3.63	3.31	1.20	1.09	2.63	-
Available Ni mg kg^{-1}	Mean cult.	0.74	0.39	0.19	0.29	0.34	-
	Mean cont.	0.91	0.47	0.18	0.26	0.28	-
Available Cd mg kg^{-1}	Mean cult.	0.11	0.07	0.08	0.10	0.19	-
	Mean cont.	0.30	0.10	0.09	0.05	0.06	-
Available Pb mg kg^{-1}	Mean cult.	2.69	5.01	5.25	25.70	5.01	-
	Mean cont.	1.45	8.51	6.61	18.20	4.57	-

Back-transformed means (in original units) from Table C1 obtained by applying the inverse function used to transform the data.

REFERENCES

Abay, F., Teshome, B., Hailu, M. and Lemma, M. (2001). Facilitating farmer-to-farmer communication about innovation in Tigray. In: *Farmer Innovation in Africa—A source of inspiration for agricultural development* (Reji, C. and Waters-Bayer, A., eds.), pp.185-197. London, U.K.: Earthscan Publications Ltd.

Adams, D.W. and Von Pischke, J.D. (1992). Microenterprise credit programs: déjà vu. *World Development* **20**:1463-1470.

Adepetu, A.A. (1985). *Farmers and their farms on four fadamas on Jos Plateau.* Jos Plateau Environmental Resources Development Programme, Interim Report No. 2. University of Durham, Durham, U.K.

Adriano, D.C. and Weber, J.T. (2001). Influence of fly ash on soil physical properties and turfgrass establishment. *Journal of Environmental Quality* **30**:596-601.

Agbenin, J.O. and Goladi, J.T. (1997). Carbon, nitrogen and phosphorous dynamics under continuous cultivation as influenced by farmyard manure and inorganic fertilizers in the savanna of northern Nigeria. *Agriculture, Ecosystems and Environment* **63**:17-24.

Agunwamba, J.C. (1998). Solid waste management in Nigeria: problems and issues. *Environmental Management* **22**:849-856.

Agunwamba, J.C. (2001). Analysis of socio-economic and environmental impacts of waste stabilization pond and unrestricted wastewater irrigation: interface with maintenance. *Environmental Management* **27**:463-476.

Ahmed, S.M. and Chowdhury, M. (2001). Micro-credit and emotional well-being: experience of poor rural women from Matlab, Bangaldesh. *World Development* **29**:1957-1966.

Alaimo, M.G., Dongarra, G., Melati, M.R., Monna, F. and Varrica, D. (2000). Recognition of environmental trace metal contamination using pine needles as bioindicators—The urban area of Palermo (Italy). *Environmental Geology* **39**:914-924.

Alexander, M.J. (1984). *Soil development on mine spoil and reclaimed areas of the Jos Plateau.* Jos Plateau Environmental Resources Development Programme, Interim Report No. 1. University of Durham, Durham, U.K.

Alexander, M.J. (1985). *An historical introduction to the reclamation of mineland on the Jos Plateau.* Jos Plateau Environmental Resources Development Programme, Interim Report No. 4. University of Durham, Durham, U.K.

Alexander, M.J. (1986). *Soil characteristics and the factors influencing their development on mine spoil of the Jos Plateau.* Jos Plateau Environmental Resources Development Programme, Interim Report No. 11. University of Durham, Durham, U.K.

Alexander, M.J. (1992). The long term impact of irrigated agriculture on the fertility of mineland soils. In: *Proceedings of an international seminar—On the phase II (1988-1992) training and research activities of the programme* (Schoeneich, K., Morgan, W.T.W., Olaniyan, J.A., Phillips-Howard, K. and Dung, J.E., eds.), Jos Plateau Environmental Resources Development Programme. University of Durham, Durham, U.K.

Alexander, M.J. (1996). The effectiveness of small-scale irrigated agriculture in the reclamation of mine land soils on the Jos Plateau of Nigeria. *Land Degradation & Development* **7**:77-85.

Alexander, M.J. (2000). *Fundamentals of soil science—Laboratory Handbook.* Department of Geography, University of Durham, Durham, U.K.

Alexander, M.J. and Kidd, A.D. (2000). Farmers capability and institutional incapacity in reclaiming disturbed land on the Jos Plateau, Nigeria. *Journal of Environmental Management* **59**:141-155.

Alexandratos, N. (1995). *World Agriculture: Towards 2010—A FAO Study.* Chichester, U.K.: FAO and John Wiley and Sons.

Alford, M.T., Hill, I.D., Rackham, L.J. and Tuley, P. (1979). *The Jos Plateau—A survey of environment and land use* (Morgan, W.T.W. ed.). Occasional Publications (New Series) No 14. Department of Geography, University of Durham, Durham, U.K.

Allen, A. (2001). *Environmental planning and management of the peri-urban interface (PUI): persepectives on an emerging field.* Rural-Urban Encounters: Managing the Environment of the Peri-Urban Interface. DPU International Conference, London, U.K., 9-10 November, 2001.

Allison, M., Harris, P.J.C., Hofny-Collins, A.H. and Stevens, W. (1998). *A review of the use of urban waste in peri-urban interface production systems.* Coventry: DFID and The Henry Doubleday Research Association.

Alloway, B.J. (1990). *Heavy metals in soils.* Glasgow, U.K.: Blackie and Son, Ltd.

Anikwe, M.A.N. (2000). Amelioration of a heavy clay loam soil with rice husk dust and its effect on soil physical properties and maize yield. *Bioresource Technology* **74**:169-173.

Asomani-Boateng, R. and Haight, M. (1999). Reusing organic solid waste in urban farming in African cities: a challenge for urban planners. In: *Agriculture urbaine en Afrique de l'Ouest. Une contribution à la sécurité alimentaire et à l'assainissement des villes / Urban Agriculture in West Africa. Contributing to Food Security and Urban Sanitation.* (Smith, O.B., ed.). Ottawa, Canada: CRDI/CTA.
Accessed 09/11/99 at: http://www.crdi.ca/books/focus/890/13aAsoma.html

Bahemuka, T.E. and Mubofu, E.B. (1999). Heavy metals in edible green vegetables grown along the sites of the Sinza and Msimbazi rivers in Dar es Salaam, Tanzania. *Food Chemistry* **66**:63-66.

Berrow, M.L. and Burridge, J.C. (1980). Trace element levels in soils: effects of sewage sludge. In: *Inorganic pollution and agriculture* (MAFF, ed.), pp.159-183. Series: Ministry of Agriculture, Fisheries and Food Reference Book 326. London, U.K.: HMSO

Bingham, F.T. and Page, A.L. (1975). Cadmium accumulation by economic crops. In: *International Conference on Heavy Metals in the Environment. Symposium Proceedings,* Volume II, part 1, (Hutchinson, T.C., Epstein, S., Page, A.L., Van Loon, J. and Davey, T., eds.), pp.433-441. Toronto, Ontario, Canada, October 27-31, 1975.

Binns, T. and Lynch, K. (1998). Feeding Africa's growing cities into the 21st century: the potential of urban agriculture. *Journal of International Development* **10**:777-793.

Brady, N.C. and Weil, R.R. (1999). *The nature and properties of soils,* 12th edn. Upper Saddle River, New Jersey, U.S.A.: Prentice-Hall, Inc.

Brook, R.M. and Davila, J.D. (2000). *The peri-urban interface: a tale of two cities.* School of Agricultural and Forest Sciences, University of Wales and Development Planning Unit, University College London. Bethesda, Gwynedd, Wales, U.K.: Gwasg Ffrancon Printers.

Brooks, R.R. (1998). General introduction. In: *Plants that hyperaccumulate heavy metals: their role in phytoremediation, microbiology, archaeology, mineral exploration and phytomining* (Brooks, R.R., ed.), pp.1-14. Wallingford, U.K.: CAB International.

Brummett, R.E. (1994). *Aquaculture policy options for integrated resource management in Subsaharan Africa.* ICLARM, Phillipines. Eschborn, Germany: GTZ.

Burrell, A., Hill, B. and Medland, J. (1990). *Agrifacts: A handbook of U.K. and EEC agricultural and food statistics.* Hertfordshire, U.K.: Harvester Wheatsheaf.

CEM, (2000). *Applications Disks. Method 3051- Microwave assisted acid digestion of sediments, sludges, soils and oil.* Revision O- September 1994.

Chambers, R. (1983). *Rural development: putting the last first.* London, U.K.: Longman Scientific and Technical.

Chambers, R., Pacey, A., Thrupp, L.A. (1989). *Farmer First—Farmer innovation and agricultural research.* London, U.K.: Intermediate Technology Publications.

Cheema, S.S., Dung, S., Barshep, A. and Habu, J. (1996). *Package of crop production practices for Plateau State.* Nigeria: Plateau Agricultural Development Programme.

Cline Cole, R.A., Falola, J.A., Main, H.A.C., Mortimore, M.J., Nichol, J.E., O'Reilly, F.D. (1990). *Woodfuel in Kano.* Tokyo, Japan: United Nations University Press.

Cofie, O., Dreschel, P., Amoah, P., Danso, G. and Gyiele, L. (2001). *Improving rural-urban nutrient flows through urban and peri-urban agriculture.* Rural-Urban Encounters: Managing the Environment of the Peri-Urban Interface. DPU International Conference, London, U.K., 9-10 November, 2001.

Commission Decision 98/448/EC

Connor, G.A. (1988). Use and misuse of the DTPA soil test. *Journal of Environmental Quality* **17**:715-718.

Council Directive 86/278/EEC

Council Directive 98/82/EC

Dabi, D.D. (1992). An evaluation of farming activities on the Jos Plateau Mineland. In: *Proceedings of an international seminar—On the phase II (1988-1992) training and research activities of the programme* (Schoeneich, K., Morgan, W.T.W., Olaniyan, J.A., Phillips-Howard, K. and Dung, J.E., eds.), Jos Plateau Environmental Resources Development Programme. University of Durham, Durham, U.K.

Dahnke, W.C. and Johnson, G.V. (1990). Testing soils for available nitrogen. In: *Soil testing and plant analysis* (Westerman, R.L., ed.), pp.127-139. SSSA Book Series: 3. Madison, Wisconsin, U.S.A.: SSSA Book Series.

Dalsgaard, A. and Olsen, J. E. (1995). Prevalence of Salmonella in dry pelleted chicken manure sample obtained form shrimp farms in a major shrimp production area in Thailand. *Aquaculture* **136**: 291-295.

Danfulani, U.H.D. and Fwatshak, S.U. (2002). Briefing: the September 2001 events in Jos, Nigeria. *African Affairs* **101**:243-255.

Davies, G.R. (1980). Pot experiments testing zinc, copper and nickel salts on the growth and composition of crops. In: *Inorganic pollution and agriculture* (MAFF, ed.), pp.191-204. Series: Ministry of Agriculture, Fisheries and Food Reference Book 326. London, U.K.: HMSO.

Déportes, I., Benoit-Guyod, J-L. and Zmirou, D. (1995). Hazard to man and the environment posed by the use of urban waste compost: a review. *The Science of the Total Environment* **172**:197-222.

Diaz-Chavez, R.A. and Wathern, P. (2001). *A proposed framework for sustainable development indicators for peri-urban areas. A case study of Mexico City.* Rural-Urban Encounters: Managing the Environment of the Peri-Urban Interface. DPU International Conference, London, U.K., 9-10 November, 2001.

Drechsel, P., Cofie, O., Vazquez, R. and Danso, G. (2002). *Technology development for municipal organic waste recycling for urban and peri-urban agriculture—A holistic approach.* E-conference, 2-14 February 2002 at www.ruaf.org

Dytham, C. (1999). *Choosing and using statistics: a biologist's guide.* Oxford, U.K.: Blackwell Science Ltd.

Egziabher, A.G., Lee-Smith, D., Maxwell, D.G., Memon, P.A., Mougeot, L.J.A., and Sawio, C.J. (1994). *Cities feeding people.* Ottawa, Canada: IDRC.

El-Mogazi, D., Lisk, D. and Weinstein, L.H. (1988). A review of the physical, chemical and biological properties of fly ash and effects on agricultural ecosystems. *The Science of the Total Environment* **74**:1-37.

Esrey, S.A. and Andersson, I. (2001). Ecological sanitation—Closing the loop. *Urban Agriculture Magazine* **3**:35-37.

FAO (1979). *Soil survey investigations for irrigation.* Soils Bulletin No. 42. Rome: FAO.

FAO (2000a). http://www.fao.org/unfao/bodies/COAG/COAG15/X0076e.htm
Accessed 23/01/00.

FAO (2000b). http://apps.fao.org/page/collections?subset=agriculture).

FAO-Unesco (1974). *Soil map of the world, Vol 1, Legend.* Paris: Unesco.

FAO-Unesco (1990). *Soil map of the world: revised legend.* Rome: FAO.

FAO/WHO (2001). *Report on the 32nd session of the Codex Committee on Food Additives and Contaminants, Bejing, People's Republic of China, 20-24 March 2000, ALINORM 01/12.* Joint FAO/WHO Food Standard Programme, Codex Alimentarius Commission, 24th Session, 2-7 July, 2001, Geneva, Switzerland.

Foth, H.D. and Ellis, B.G. (1997). *Soil fertility.* Boca Raton, Florida, U.S.A.: CRC Lewis Publishers.

Freund, W. (1981). *Labour and capital in the Nigerian tin mines.* London, U.K.: Heinemann.

FUA (2001). *Programme for the Official Commissioning Ceremony of 2500 stalls: Fadama Users' Association (FUA) Market in Plateau State.* Jos, Nigeria: Zimek Communications.

Furedy, C. (2001). Reducing health risks of urban organic solid waste use. *Urban Agriculture Magazine* **3**:23-25.

Gardner, G. (1998). Recycling organic wastes. In: *State of the world 1998: a Worldwatch Institute report on progress towards a sustainable society* (Brown, L.R., Flavin, C. and French, H.F., eds.), pp.96-112. London, U.K.: Earthscan.

Gbadegesin, A. (1991). Farming in the urban environment of a developing nation—A case study from Ibaden metropolis in Nigeria. *The Environmentalist* **11**:105-111.

Ghodrati, M., Sims, J.T. and Vasilas, B.L. (1995). Evaluation of fly ash as a soil amendment for the Atlantic coastal plain:I. Soil hydraulic properties and elemental leaching. *Water, Air and Soil Pollution* **81**:349-361.

Goldin, A., Bigelow, C. and Veneman, P.L.M. (1992). Concentrations of metals in ash from municipal solid waste combusters. *Chemosphere* **24**:271-280.

Gorman, J.M., Sencindiver, J.C., Horvath, D.J., Singh, R.N. and Keefer, R.F. (2000). Erodibility of fly ash used as a topsoil substitute in mineland reclamation. *Journal of Environmental Quality* **29**:805-811.

Gray, K.R. and Biddlestone, A.J. (1980). Agricultural use of composted town refuse. In: *Inorganic pollution and agriculture* (MAFF, ed.), pp.279-305. Series: Ministry of Agriculture, Fisheries and Food Reference Book 326. London, U.K.: HMSO.

Greger, M., Johansson, M., Stihl, A. and Hamza, K. (1993). Foliar uptake of Cd by pea (*Pisum sativum*) and sugar beet (*Beta vulgaris*). *Physiologia Plantarum* **88**:563-570.

Gueye, N.F.D. and Sy, M. (2001). The use of wastewater for urban agriculture—The case of Dakar, Nouakchott and Ouagadougou. *Urban Agriculture Magazine* **3**:30-32.

Gupta, A.K. (1989). Scientists' views of farmers' practices in India: barriers to effective interaction. In: *Farmer first—Farmer innovation and agricultural research* (Chambers, R., Pacey, A. and Thrupp, L.A., eds.), pp.24-31. London, U.K.: Intermediate Technology Publications.

Hansen, J.W. (1996). Is agricultural sustainability a useful concept? *Agricultural Systems* **50**:117-143.

Haramata (1991). What a load of garbage can do for your crops. *Haramata* **12**:5.

Harris, Frances M.A. '*Nutrient dynamics of the farming system of the Kano close-settled zone, Nigeria*'. (Cambridge Univ. PhD Thesis, 1995)

Harris, F.M.A. (1998). Farm-level assessment of the nutrient balance in northern Nigeria. *Agriculture, Ecosystems and Environment* **71**:201-214.

Harris, F. (2002). Management of manure in farming systems in semi-arid West Africa. *Experimental Agriculture* **38**:131-148.

Harris, F. and Dung, J. (2000). Irrigated vegetable production on the Jos Plateau: an assessment of environmental constraints. In: *Rural access issues and the supply of urban food markets in Nigeria: focus on market access for smallholder vegetable producers on the Jos Plateau* (Porter, G., ed.), Appendix 4. Final Technical Report, Crop Harvest Programme R7924 (ZB0256).

Harris, F. and Yusuf, M.A. (2001). Manure management by smallholder farmers in the Kano close-settled zone, Nigeria. *Experimental Agriculture* **37**:319-332.

Harriss, J. (2002). The case for cross-disciplinary approaches in international development. *World Development* **30**:487-496.

Hart, D. and Pluimers, J. (1996). *Wasted agriculture—The use of compost in urban agriculture.* Urban Waste Expertise Programme, Composting of Organic Household Waste, UWEP Working Document 1. Gouda, the Netherlands: WASTE.

Hesse, P.R. (1971). *A textbook of soil chemical analysis*. London, U.K.: John Murray.

Hill, I.D. and Rackham, L.J. (1973). *The land resources of Central Nigeria—Phase 1. Interim Report on the land forms, soils and vegetation of the Jos Plateau.* Volume 1 Land Forms and Soils. Miscellaneous Report 153. Surbiton, U.K.: Land Resources Division.

Hoffman, I., Gerling, D., Kyiogwom, U.B. and Mané-Bielfeldt, A. (2001). Farmers' management strategies to maintain soil fertility in a remote area in northwest Nigeria. *Agriculture, Ecosystems and Environment* **86**:263-275.

http://europa.eu.int/comm/environment/sludge/sludge_pollutants.pdf

http://profiler.bgu.ac.il/resco/Funding%20Sources/EU%205fw/medaCall4Propo.html

ICRCL 59/83 (1987). *Guidance on the assessment and redevelopment of contaminated land.* Interdepartmental Committee on the Redevelopment of Contaminated Land, ICRCL Guidance Note 59/83, 2nd edn. London, U.K.: Department of the Environment.

Ihemegbulem, V.C., Mabur, E.J., Phillips-Howard, K.D. and Schoeneich, K. (1992). *Potential use of Jos Plateau mine dams: especially for irrigation.* Jos Plateau Environmental Resources Development Programme, Interim Report No. 28. University of Durham, Durham, U.K

Jackson, C. (2002). Disciplining gender? *World Development* **30**:497-509.

James, D.W. and Wells, K.L. (1990). Soil sample collection and handling: Technique based on source and degree of field variability. In: *Soil testing and plant analysis* (Westerman, R.L., ed.), pp. 25-71. SSSA Book Series: 3. Madison, Wisconsin, U.S.A.: SSSA Book Series.

Johnes, P.J. and Heathwaite, A.L. (1992). A procedure for the simultaneous determination of total nitrogen and total phosphorus in freshwater samples using persulphate microwave digestion. *Water Research* **26**:1281-1287.

Keppel, Geoffrey (1991). *Design and analysis : a researcher's handbook.* London, U.K.: Prentice-Hall.

Korn, M. (1996). The Dike-Pond concept: sustainable agriculture and nutrient recycling in China. *Ambio* **25**:6-13.

Kundu, N. (1995). Urban solid waste recycling through vegetable cultivation and rag picking— A study in Calcutta. In: *R'95 Congress Proceedings: Recovery, Recycling, Reintegration,* Vol. 4 (Barrage, A. and Edelmann, X., eds.), pp. 233-238 Geneva: EMPA.

Kundu, N., Konar, P. and Basu, A. (2001). *Peri-urban agriculture and environmental management: Kolkata experience.* Rural-Urban Encounters: Managing the Environment of the Peri-Urban Interface. DPU International Conference, London, U.K., 9-10 November, 2001.

Landon, J.R. (ed.). (1984). *Booker Tropical Soil Manual: A handbook for soil survey and agricultural evaluation in the tropics and subtropics.* Booker Agriculture International Limited. Harlow, U.K.: Longman.

Lardinois, I. and van de Klundert, A. (1994a). Recycling urban organics in Asia and Africa. *Biocycle* **June**:56-58.

Lardinois, I. and van de Klundert, A. (1994b). Recovery of organic wastes in cities. *ILEIA Newsletter* **10**: 6-8.

Lekasi, J.K., Tanner, J.C., Kimani, S.K. and Harris, P.J.C. (1998). *Manure management in the Kenya Highlands: practices and potential.* DFID, NRSP, HDRA, ILRI, KARI. Kenilworth, U.K.: Emerson Press.

Lewcock, C.P. (1994). *Case study of the use of urban waste by near-urban farmers of Kano, Nigeria.* Project No. A0354. Chatham, Kent, U.K: NRI.

Lewcock, C.P. (1995). Farmer use of urban waste in Kano. *Habitat International* **19**:225-234.

Lightfoot, C., Prein, M. and Lopez, T. (1994). Bioresource flow modelling with farmers. *ILEIA Newletter* **10**:22-23.

Lindsay, W.L. and Norvell, W.A. (1978). Development of a DTPA soil test for zinc, iron, manganese, and copper. *Journal of the Soil Science Society of America* **42**:421-428.

Ling, B. (1994). Safe use of treated night soil. *ILEIA Newsletter* **10**:10-11.

Lisk, D.J. (1988). Environmental implications of incineration of municipal solid waste and ash disposal. *The Science of the Total Environment* **74**:39-66.

Little, D.C., Surintaraseree, P., Innes-Taylor, N. (1996). Fish culture in rainfed rice fields of northeast Thailand. *Aquaculture* **140**:295-321

Lock, K. and van Veenhuizen, R. (2001). Balancing the positive and negative health impacts. *Urban Agriculture Magazine* **3**:1-5.

Lupwayi, N.Z., Girma, M. and Haque, I. (2000). Plant nutrient contents of cattle manures from scall-scale farms and experimental stations in the Ethiopian highlands. *Agriculture, Ecosystems and Enviornment* **78**:57-63.

Lynch, K., Binns, T. and Olofin, E. (2001). Urgan agriculture under threat: the land security question in Kano, Nigeria. *Cities* **18**:159-171.

MAFF (1981). *Lime and liming.* Series: Ministry of Agriculture, Fisheries and Food Reference Book 35. London, U.K.: HMSO.

MAFF (1986). *The analysis of agricultural materials: a manual of the analytical methods used by the Agricultural Development and Advisory Service.* Series: Ministry of Agriculture, Fisheries and Food Reference Book 427. London, U.K.: HMSO.

MAFF (2000). *Fertiliser recommendations for agricultural and horticultural crops.* Series: Ministry of Agriculture, Fisheries and Food Reference Book 209. London, U.K.: HMSO.

Martin, M.H., Coughtrey, P.J., Shales, S.W. and Little, P. (1980). Aspects of airborne cadmium contamination of soils and natural vegetation. In: *Inorganic pollution and agriculture* (MAFF, ed.), pp.56-69. Series: Ministry of Agriculture, Fisheries and Food Reference Book 326. London, U.K.: HMSO.

Maurya, D.M. (1989). The innovative approach of Indian farmers. In: *Farmer first-Farmer innovation and agricultural research* (Chambers, R., Pacey, A. and Thrupp, L.A., eds.), pp.9-14. London, U.K.: Intermediate Technology Publications.

Maxwell, D.G. (1994). The household logic of urban farming in Kampala. In: *Cities feeding people.* (Egziabher, A.G., Lee-Smith, D., Maxwell, D.G., Memon, P.A., Mougeot, L.J.A., and Sawio, C.J., eds.), pp.47-65. Ottawa, Canada; IDRC.

Mbagwu, J.S.C. (1992a). Improving the productivity of a degraded ultisol in Nigeria using organic and inorganic amendments. Part 1: Chemical properties and maize yield. *Bioresource Technology* **42**:149-154.

Mbagwu, J.S.C. (1992b). Improving the productivity of a degraded ultisol in Nigeria using organic and inorganic amendments. Part 2: Changes in physical properties. *Bioresource Technology* **42**:167-175.

Mbagwu, J.S.C., Unamba-Oparah, I. and Nevoh, G.O. (1994). Physico-chemical properties and productivity of two tropical soils amended with dehydrated swine waste. *Bioresource Technology* **49**:163-171.

Mbiba, B. (2001). *Peri-urban transformations and livelihoods in East and Southern Africa: Insights from the peri-net research experience.* Rural-Urban Encounters: Managing the environment of the Peri-Urban Interface. DPU International Conference, London, U.K., 9-10 November 2001.

Mbiba, B. and Van Veenhuizen, R. (2001). The integration of urban and peri-urban agriculture into planning. *Urban Agriculture Magazine* **4**:1-6.

McGarry, M.G. (1976). The taboo resource-the use of human excreta in Chinese agriculture. *The Ecologist* **6**:150-154.

McLaughlin M.J., Hamon, R.E., McLaren, R.G., Speir, T.W. and Rogers, S.L. (2000). Review: A bioavailability-based rationale for controlling metal and metalloid contamination of agricultural land in Australia and New Zealand. *Australian Journal Of Soil Research* **38**:1037-1086.

Miruts, G. and Abay, F. (2001). Farmer-led experimentation in the drylands of Central Tigray. In: *Farmer Innovation in Africa—A source of inspiration for agricultural development* (Reji, C. and Waters-Bayer, A., eds.), pp.234-247. London, U.K.: Earthscan Publications Ltd.

Møberg, J.P., Esu, I.E. and Malgwi, W.B. (1991). Characteristics and constituent composition of Harmattan dust falling in Northern Nigeria. *Geoderma* **48**:73-81.

Morgan, K. and Murdoch, J. (2002). Organic vs. conventional agriculture: knowledge, power and innovation in the food chain. *Geoforum* **31**:159-173.

Mortimore, M.J. (1967). Land and population pressure in the Kano close-settled zone, Northern Nigeria. *Advancement of Science* **23**:677-686.

Mosley, P. and Hulme, D. (1998). Microenterprise finance: is there a conflict between growth and poverty alleviation? *World Development* **26**:783-790.

Mougeot, J.L.A. (1994a). African city farming from a world perspective. In: *Cities feeding people* (Egziabher, A.G., Lee-Smith, D., Maxwell, D.G., Memon, P.A., Mougeot, L.J.A., and Sawio, C.J., eds.), pp.1-24. Ottawa, Canada: IDRC.

Mougeot, J.L.A. (1994b). Leading urban agriculture into the 21st Century: renewed institutional interest. In: *Cities feeding people* (Egziabher, A.G., Lee-Smith, D., Maxwell, D.G., Memon, P.A., Mougeot, L.J.A., and Sawio, C.J., eds.), pp.105-115. Ottawa, Canada : IDRC.

Moustier, P. (2000). Complémentarité entre agriculture urbaine et agriculture rurale. In: *Agriculture urbaine en Afrique de l'Ouest. Une contribution à la sécurité alimentaire et à l'assainissement des villes / Urban Agriculture in West Africa. Contributing to Food Security and Urban Sanitation.* (Smith, O.B., ed.). Ottawa, Canada: CRDI/CTA.
Accessed 16/11/00 at http://www.idrc.ca/books/focus/890/07aMoust.html

Mudimu, G.D. (1996). Urban agricultural activities and women's strategies in sustaining family livelihoods in Harare, Zimbabwe. *Singapore Journal of Tropical Geography* **17**:179-194.

Mukherjee, M., Nath, U., Kashem, Sk. A. and Chattopadhyay, M. (2001). *The sewage fed fisheries in Kolkata.* Rural-Urban Encounters: Managing the Environment of the Peri-Urban Interface. DPU International Conference, London, U.K., 9-10 November, 2001.

Niang, S. (1999). Utilisation des eaux useés brutes dans l'agriculture urbaine au Sénégal:bilan et perspectives. In: *Agriculture urbaine en Afrique de l'Ouest. Une contribution à la sécurité alimentaire et à l'assainissement des villes / Urban Agriculture in West Africa. Contributing to Food Security and Urban Sanitation.* (Smith, O.B., ed.). Ottawa, Canada: CRDI/CTA. Accessed 09/11/99 http://www.crdi.ca/books/focus/890/11aNiang.html

Nielsen, F. (2001). Why do farmers innovate and why don't they innovate more? In: *Farmer innovation in Africa—A source of inspiration for agricultural development* (Reij, C. and Waters-Bayer, A., eds.), pp. 92-103. London, U.K.: Earthscan Publications Ltd.

Norvell, W.A. (1984). Comparison of chelating agents as extractants for metals in diverse soil materials. *Journal of the Soil Science Society of America* **48**:1285-1292.

Okali, C., Sumberg, J. and Farrington, J. (1994). *Farmer participatory research—Rhetoric and reality.* London, U.K.: Intermediate Technology Publications.

Olaniyan, J.A.O. (1992). General introduction to Phase 2 activities. In: *Proceedings of an international seminar—On the phase II (1988-1992) training and research activities of the programme* (Schoeneich, K., Morgan, W.T.W., Olaniyan, J.A., Phillips-Howard, K. and Dung, J.E., eds.), Jos Plateau Environmental Resources Development Programme. University of Durham, Durham, U.K.

Olofin, E. (1996). Socio-economic sustainability of the fadama system in the drylands of Nigeria. *Geography* **81**: 377-380.

Owusu-Bennoah, E. and Visker, C. (1994). Organic wastes hijacked. *ILEIA Newsletter* **10**:12-13.

PADP/NADP. (1998). *Internal Implementation Completion Report of National Fadama Development Facility (NFDF).* Loan No 3451-UNI. Jos, Nigeria: Plateau/Nasarawa Agricultural Development Programme (PADP/NADP).

Page, B. (2002). Urban agriculture in Cameroon: an anti-politics machine in the making? *Geoforum* **33**:41-54.

Parkinson, J. and Tayler, K. (2001). *Sanitation and wastewater management in peri-urban areas: opportunities and constraints in developing countries.* Rural-Urban Encounters: Managing the Environment of the Peri-Urban Interface. DPU International Conference, London, U.K., 9-10 November, 2001.

Pascual, J.A., Ayuso, M., Garcia, C. and Hernandez, T. (1997). Characterization of urban wastes according to fertility and phytotoxicity parameters. *Waste Management and Research* **15**:103-112.

Patterson, G. (1986). Tin mine ponds of the Jos Plateau—Their nature and resource value. Jos Plateau Environmental Resources Development Programme, Interim Report No. 8. University of Durham, Durham, U.K.

Peijnenburg, W., Baerselman, R., de Groot, A., Jager, T., Leenders, D., Posthuma, L. and Van Veen, R. (2000). Quantification of metal bioavailability for lettuce (*Lactuca sativa* L.) in field soils. *Archives of Environmental Contamination and Toxicology* **39**: 420-430.

Phillips-Howard, K.D. (1992a). Physical environment and resource use on the Jos Plateau. In: *Proceedings of an international seminar—On the phase II (1988-1992) training and research activities of the programme* (Schoeneich, K., Morgan, W.T.W., Olaniyan, J.A., Phillips-Howard, K. and Dung, J.E., eds.), Jos Plateau Environmental Resources Development Programme. University of Durham, Durham, U.K.

Phillips-Howard, K.D. (1992b). Trials and pilot-projects to promote agriculture on mineland. In: *Proceedings of an international seminar—On the phase II (1988-1992) training and research activities of the programme* (Schoeneich, K., Morgan, W.T.W., Olaniyan, J.A., Phillips-Howard, K. and Dung, J.E., eds.), Jos Plateau Environmental Resources Development Programme. University of Durham, Durham, U.K.

Phillips-Howard, K.D. (1994). Training and visit extension and fertiliser use: the case of the Jos Plateau, Nigeria. *Applied Geography* **14**:245-263.

Phillips-Howard, K.D., Adepetu, A.A. and Kidd, A.D. (1990). *Aspects of change in fadama farming along the Delimi river, Jos L.G.C. (1982-1990).* Jos Plateau Environmental Resources Development Programme, Interim Report No. 18. University of Durham, Durham, U.K.

Phillips-Howard, K.D. and Kidd, A.D. (1990). *Significance of indigenous knowledge systems to the improvement of dry-season farming on the Jos Plateau.* Jos Plateau Environmental Resources Development Programme, Interim Report No. 17. University of Durham, Durham, U.K.

Phillips-Howard, K.D. and Kidd, A.D. (1991). *Knowledge and management of soil fertility among dry season farmers on the Jos Plateau, Nigeria.* Jos Plateau Environmental Resources Development Programme, Interim Report No. 25. University of Durham, Durham, U.K.

Phillips-Howard, K.D. and Lyon, F. (1994). Agricultural intensification and the threat to soil fertility in Africa: evidence from the Jos Plateau, Nigeria. *The Geographical Journal* **160**:252-265.

Phillips-Howard, K.D. and Schoeneich, K. (1992). *The irrigation potential of water resources on the Jos Plateau: a preliminary analysis.* Jos Plateau Environmental Resources Development Programme, Interim Report No. 27. University of Durham, Durham, U.K

Pichtel, J.R., Dick, W.A. and Sutton, P. (1994). Comparison of amendments and management practices for long-term reclamation of abandoned mine lands. *Journal of Environmental Quality* **23**:766-772.

Porter, G. (1992a). *Food marketing and urban food supply on the Jos Plateau: a comparison of large and small producer strategies under 'SAP'.* Jos Plateau Environmental Resources Development Programme, Interim Report No. 29. University of Durham, Durham, U.K

Porter, G. (1992b). *Rural markets on the Jos Plateau.* Jos Plateau Environmental Resources Development Programme, Interim Report No. 31. University of Durham, Durham, U.K

Porter, G. (2001). *Rural access issues and the supply of urban food markets in Nigeria: focus on market access for smallholder vegetable producers on the Jos Plateau.* Final Technical Report, Crop Harvest Programme R7924 (ZB0256).

Porter, G., Harris, F., Lyon, F., Dung, J. and Adepetu, A.A. (2002). *Markets, ethnicity and environment in a vulnerable landscape: the case of small-scale vegetable production on the Jos Plateau, Nigeria, 1991-2001.* Conference Paper of the RGS/IBG, Queens University, Belfast, 2-6 January 2002.

Pottier, J. (1994). Agricultural discourses: farmer experimentation and agricultural extension in Rwanda. In: *Beyond farmer first* (Scoones, I. and Thompson, J., eds.), p.83-88. London, U.K.: Intermediate Technology Publications.

Prain, G. and de Zeeuw, H. (2002). *Week 1 Summary of Topic 4 Methods for Participatory Technology Development in Urban Agriculture.* RUAF E-conference on 'Appropriate methods for urban agriculture: research, policy development, planning, implementation and evaluation'. 4-16 Feburary, 2002 at www.ruaf.org

Prasad, R. and Power, J.F. (1997). *Soil fertility management for sustainable agriculture.* Boca Raton, Florida, U.S.A.: CRC Lewis Publishers.

Prinsloo, J.F., and Schoonbee, H.J. (1987). The use of sheep manure as nutrient with fish feed in pond fish polyculture in Transkei South Africa. *Water S A (Pretoria)* **13**:119-124.

Quansah, C., Drechsel, P. and Lefroy, R.D.B. (1997). Agricultural production systems of the peri-urban interface: soil-fertility issues. In: *Integrated nutrient management on farmers' fields: approaches that work* (Gregory, P.J., Pilbearn, C.J. and Walker, S.H., eds.), pp.199-209. Reading, U.K.: The Department of Soil Science, The University of Reading, Occasional Publication Number 1.

Quevauviller, P., Lachica, M., Barahona, E., Rauret,E.G., Ure,A., Gomez, A. and Muntau, A.H. (1996). Interlaboratory comparison of EDTA and DTPA procedures prior to certification of extractable trace elements in calcareous soil. *The Science of the Total Environment* **178**: 127-132.

Rahman, A. (1999). Micro-credit initiatives for equitable and sustainable development: who pays? *World Development* **27**:67-82.

Raskin, I. and Ensley, B.D. (Eds.) (2000). *Phytoremediation of toxic metals: using plants to clean up the environment.* John Wiley & Sons, New York.

Reij, C. and Waters-Bayer, A. (2001a). Entering research and development in land husbandry through farmer innovation. In: *Farmer innovation in Africa—A source of inspiration for agricultural development* (Reij, C. and Waters-Bayer, A., eds.), pp. 3-22. London, U.K.: Earthscan Publications Ltd.

Reij, C. and Waters-Bayer, A. (2001b). An initial analysis of farmer innovators and their innovations. In: *Farmer innovation in Africa—A source of inspiration for agricultural development* (Reij, C. and Waters-Bayer, A., eds.), pp. 3-22. London, U.K.: Earthscan Publications Ltd.

Rhoades, R. (1989). The role of farmers in the creation of agricultural technology. In: *Farmer first-Farmer innovation and agricultural research* (Chambers, R., Pacey, A. and Thrupp, L.A., eds.), pp.3-9. London, U.K.: Intermediate Technology Publications.

Rigby, D. and Cáceres, D. (2001). Organic farming and the sustainability of agricultural systems. *Agricultural Systems* **68**:21-40.

Risser, J.A. and Baker, D.E. (1990). Testing soils for toxic metals. In: *Soil testing and plant analysis*, (Westerman, R.L., ed.), pp. 25-71. SSSA Book Series: 3. Madison, Wisconsin, U.S.A: SSSA Book Series.

Rowell, D.L. (1994). *Soil Science: Methods and Applications*. Harlow, U.K.: Longman.

Sá Carvalho, de, L.C., Esteves Rodrigues, M. and Diaz Paret, B. *Tacit and formal knowledge and learning in small business: an exploratory study on the perceptions of successful businessmen.* Accessed 09/02 at: http://in3.dem.ist.utl.pt/downloads/cur2000/papers/s17p06.pdf

Salas, M. (1994). "The technicians only believe in science and cannot read the sky": the cultural dimension of knowledge conflict in the Andes. In: *Beyond Farmer First* (Scoones, I. and Thompson, J. eds.), p.57-69. London, U.K.: Intermediate Technology Publications.

Schalatek, L. and Unmüssig, B. (2002). The WDR 2003: a strenuous tale of missed opportunities... In: *Managing sustainability World Bank style. An evaluation of the World Development Report 2003* (Schalatek, L., ed.), pp.7-18. Republic of South Africa: Heinrich Böll Foundation.

Schoeneich, K. and Ihemegbulem, V.C. (1992). Abandoned tin-mining dams of the Jos Plateau and their potential uses. In: *Potential use of Jos Plateau mine dams: especially for irrigation* (Ihemegbulem, V.C., Mabur, E.J., Phillips-Howard, K.D. and Schoeneich, K., eds.). Jos Plateau Environmental Resources Development Programme, Interim Report No. 28. University of Durham, Durham, U.K

Schoeneich, K., Ihemegbulem, V.C. and Nyamekye, A.A. (1992). Outline of water resources management plan for Plateau State. In: *Proceedings of an international seminar—On the phase II (1988-1992) training and research activities of the programme* (Schoeneich, K., Morgan, W.T.W., Olaniyan, J.A., Phillips-Howard, K. and Dung, J.E., eds.), Jos Plateau Environmental Resources Development Programme. University of Durham, Durham, U.K.

Schumann, A.W. and Sumner, M.E. (1999). Plant nutrient availability from mixtures of fly ashes and biosolids. *Journal of Environmental Quality* **28**:1651-1657.

Scoones, I. and Thompson, J. (1994a). *Beyond Farmer First.* London, U.K.: Intermediate Technology Publications.

Scoones, I. and Thompson, J. (1994b). Knowledge, power and agriculture-towards a theoretical understanding. In: *Beyond Farmer First* (Scoones, I. and Thompson, J., eds.), p.16-32. London, U.K.: Intermediate Technology Publications.

Sharma, A.P., Singh, U.P., Chauhan, R.S., Singh, V.K. (1997). Integrated duck-cum-fish culture in Tarai region of Uttar Pradesh. In: *Ecological agriculture and sustainable development, Vols. 1 and 2.* International Conference on Ecological Agriculture: Towards Sustainable Development, Chandigarh, India, November 15-17, 1997 (Dhaliwal, G. S., et al., eds.), pp.285-292. India: Indian Ecological Society; Centre for Research in Rural and Industrial Development.

Sheskin, David (1997). *Handbook of parametric and nonparametric statistical procedures.* Boca Raton, Florida, U.S.A.: CRC Lewis Press.

Shore, K. (2000). *Restoring degraded soils in India using urban wastes.* REPORTS-Science from the Developing World, IDRC.
Accessed at: http://www.idrc.ca/reports/read_article_English.cfm?article_num=812

Sikana, P. (1994). Indigenous soil characterization in Northern Zambia. In: *Beyond Farmer First,* (Scoones, I. and Thompson, J., eds.), p.80-82. London, U.K.: Intermediate Technology Publications.

Sims, J.T., Vasilas, B.L. and Ghodrati, M. (1995). Evaluation of fly ash as a soil amendment for the Atlantic coastal plain:II. Soil chemical properties and crop growth. *Water, Air and Soil Pollution* **81**:363-372.

Singh S.P., Tack F.M. and Verloo M.G. (1998). Heavy metal fractionation and extractability in dredged sediment derived surface soils. *Water, Air, and Soil Pollution* **102**:313-328.

Smit, J. and Nasr, J. (1992). Urban agriculture for sustainable cities: using wastes and idle land and water bodies as resources. *Environment and Urbanisation* **4**:141-152.

Someshwar, A.V. (1996). Wood and combination wood-fired boiler ash characterization. *Journal of Environmental Quality* **25**:962-972.

Sonou, M. (2001). Periurban irrigated agriculture and health risks in Ghana. *Urban Agriculture Magazine* **3**:33-34.

Stephens, S.R., Alloway, B.J., Carter, J.E. and Parker, A. (2001). Towards the characterisation of heavy metals in dredged canal sediments and an appreciation of 'availability': two examples from the U.K. *Environmental Pollution* **113**:395-401.

Sterckeman, T., Gomez, A. and Ciesielski, H. (1996). Soil and waste analysis for environmental assessment in France. *Science of the Total Environment* **178**:63-69.

Sweet, L. (1999). *Room to live-Healthy cities for the urban century.* IDRC Briefing. Ottawa, Canada: IDRC.

Tacoli, C. (2001). *Livelihood impacts and strategies in the peri-urban interface: mapping out the issues.* Rural-Urban Encounters: Managing the Environment of the Peri-Urban Interface. DPU International Conference, London, U.K., 9-10 November, 2001.

Thornton, I., Butler, D., Docx, P., Hession, M., Makropoulos, C., McMullen, M., Nieuwenhuijsen, M., Pitman, A., Rautiu, R., Sawyer, R., Smith, S. and White, D. (2001). *Pollutants in urban waste water and sewage sludge-* Final report prepared by ICON, IC Consultants, London, for Directorate-General Environment, European Commission, Office for Official Pubblications of the European Communities, Luxembourg.
Accessed at: http://europa.eu.int/comm/environment/sludge/sludge_pollutants.pdf

Tiessen, H., Hauffe, H.K. and Mermut, A.R. (1991). Deposition of Harmattan dust and its influence on base saturation of soils in northern Ghana. *Geoderma* **49**:285-299.

Tinker, I. (1994). Urban agriculture is already feeding cities. In: *Cities feeding people* (Egziabher, A.G., Lee-Smith, D., Maxwell, D.G., Memon, P.A., Mougeot, L.J.A., and Sawio, C.J., eds.), pp.vii-xiv. Ottawa, Canada: IDRC.

Twyman, C., Morrison, J. and Sporton, D. (1999). The final fifth: autobiography, reflexivity and interpretation in cross-cultural research. *Area* **31.4**:313-325.

USDA. (1972). *Soil Survey Laboratory Methods and Procedures for Collecting Soil Samples.*, Soil Survey Investigation Report No. 1. Washington D.C., U.S.A.: Soil Conservation Service.

Vance, E.D. (1996). Land application of wood-fired and combination boiler ashes: an overview. *Journal of Environmental Quality* **25**:937-944.

Webber, J. (1980a). Metals in sewage sludge applied to the land and their effects on crops. In: *Inorganic pollution and agriculture* (MAFF, ed.), pp.222-234. Series: Ministry of Agriculture, Fisheries and Food Reference Book 326. London, U.K.: HMSO.

Webber, J. (1980b). Effects of zinc and cadmium added in different proportions on the growth and composition of lettuce. In: *Inorganic pollution and agriculture* (MAFF, ed.), pp.205-210. Series: Ministry of Agriculture, Fisheries and Food Reference Book 326. London, U.K.: HMSO.

Werner, J. (1993). *Participatory development of agricultural innovations—Procedures and methods of on-farm research.* Eschborn, Federal Republic of Germany: Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH.

White, H. (2002). Combining quantitative and qualitative approaches in poverty analysis. *World Development* **30**:511-522.

Williams, J.H. (1980). Effect of soil pH on the toxicity of zinc and nickel to vegetable crops. In: *Inorganic pollution and agriculture* (MAFF, ed.), pp.211-218. Series: Ministry of Agriculture, Fisheries and Food Reference Book 326. London, U.K.: HMSO.

Wong, J.W.C. and Su, D.C. (1997). Reutilization of coal fly-ash and sewage sludge as an artificial soil-mix: effects of preincubation on soil physico-chemical properties. *Bioresource Technology* **59**:97-102.

World Health Organisation (WHO). (1996). *Trace elements in human nutrition and health.* Geneva: WHO.

Yates, M.A. (1937). *The design and analysis of factorial experiments.* Technical Communication N^{0}. 35. Harpenden, U.K: Imperial Bureau of Soil Science,.

Young, A. and Brown, P. (1962). *The physical environment of Northern Nyasaland.* Zomba, Malawi: Government Printer.

Zhang, F.S., Yamasaki, S. and Nanzyo, M. (2001). Application of waste ashes to agricultural land—Effect of incineration temperature on chemical characteristics. *The Science of the Total Environment* **264**:205-214.

Zhang, F.S., Yamasaki, S. and Nanzyo, M. (2002). Waste ashes for use in agricultural production: I. Liming effect, contents of plant nutrients and chemical characteristics of some metals. *The Science of the Total Environment* **284**:215-225.

Zucconi, F. and De Bertoldi, M. (1987). Production and characterization of compost. *BioCycle* **28**:56-61.